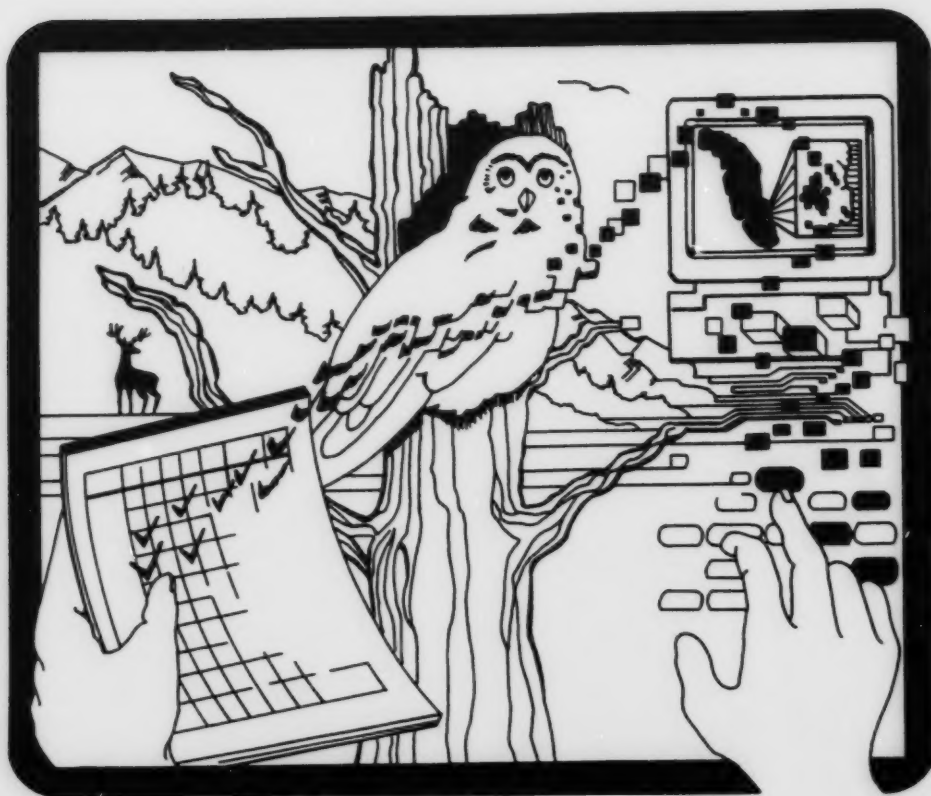

HABITAT FUTURES

Integrating Timber
and Wildlife in
Forest Landscapes:

1989

A Matter of Scale

Proceedings of a workshop at Pack Experimental Forest, Eatonville, Washington, October 16-20, 1989



*Integrating Timber and Wildlife in Forest
Landscapes: A Matter of Scale*

Proceedings of the Habitat Futures workshop at Pack Experimental
Forest, Eatonville, Washington, October 16–20, 1989

Editors: J.B. Nyberg and W.B. Kessler

September 1992

Canadian Cataloguing in Publication Data

Main entry under title:

Integrating timber and wildlife in forest
landscapes

Cover title: Habitat futures 1989.

"A second Habitat futures workshop" --Foreword.

Includes bibliographical references: p.

ISBN 0-7718-9280-2

1. Forests and forestry - Northwest, Pacific -
Multiple use - Congresses. 2. Forests and forestry
- Alaska - Multiple use - Congresses. 3. Forest
management - Northwest, Pacific - Congresses. 4.
Forest management - Alaska - Congresses. 5.
Wildlife conservation - Northwest, Pacific -
Congresses. 6. Wildlife conservation - Alaska -
Congresses. I. Nyberg, J. B. II. Kessler,
Winifred. III. British Columbia. Ministry of
Forests. IV. Title: Habitat futures 1989. V.
Title: Integrating timber and wildlife in forest
landscapes.

SD387.M8H32 1992 333.75'15'09795 C92-092357-7

© 1992 Province of British Columbia
Published by the
Research Branch
Ministry of Forests
31 Bastion Square
Victoria, B.C. V8W 3E7

Copies of this and other Ministry of Forests titles
are available from Crown Publications Inc.,
546 Yates Street, Victoria, B.C. V8W 1K8.

FOREWORD

Demands for better management of timber and wildlife continue to increase in Canada and the United States. As resource managers attempt to meet those demands they face ever more complicated decisions about forestry practices and land allocation. Researchers and managers throughout the continent are developing new conceptual approaches and technologies for evaluating habitat relations and guiding decisions about integrated forest management.

The Habitat Futures workshops have proven to be stimulating forums for exchanging ideas and constructively criticizing evolving tools and techniques for integrating timber and wildlife. The papers in this publication are the product of the second Habitat Futures workshop, held in October, 1989 at the University of Washington's Pack Experimental Forest. The focus of Habitat Futures is on the Pacific Northwest region of North America, including Alaska, British Columbia, Washington, Oregon, Idaho and Montana, but some of the tools and techniques have wider application.

The degree of development of the different tools and techniques described here varies. Some have been developed sufficiently for trial use in integrated management; others are still largely conceptual and should be fully tested before operational application. Nevertheless, all the publications provide sufficient detail for discussion, refinement, and potential modification for application to other areas.

Most often, wildlife and timber issues are addressed at one of three scales: (1) the stand (1–100 ha); (2) the watershed (1000–10 000 ha); or (3) the sub-region, such as Timber Supply Areas and Tree Farm Licenses in Canada and National Forests in the United States (100 000 ha or more). Although data and decisions must feed back and forth between these scales, different approaches are used to evaluate relationships at each one. The following papers provide examples appropriate to each scale, with emphasis on the watershed.

J.B. Nyberg and W.B. Kessler (editors)



TABLE OF CONTENTS

FOREWORD	iii
1. Evaluating Stand Conditions to Support Integrated Silvicultural Prescriptions for Timber and Wildlife: Snags and Old Growth by Martin G. Raphael, Steven L. Marquardt and Reginald H. Barrett	1
2. Modeling Forest Landscapes in Support of Integrated Resource Management and Cumulative Effects Analysis by Eddie Morris, Ben Sanders and Richard Holthausen	21
3. Managing for Wildlife Diversity In Forested Watersheds In British Columbia: The Wildlife Habitat Handbook by Andrew P. Harcombe	61
4. Assessing and Planning the Spatial and Temporal Features of Black-tailed Deer Habitat by Marvin Eng, Scott McNay, Doug Janz, Laurie Kremsater, Ian MacDougall, and Rick Page	81
5. Applying Geographic Information Systems to Support Comprehensive Land Management Planning: Experiences of the Tongass National Forest, Alaska by Lowell H. Suring, Eugene J. Degayner, III, and William H. Wilson, Jr.	113
6. Putting Data, Experience and Professional Judgment to Work in Making Land Management Decisions by Bruce G. Marcot	139





Evaluating Stand Conditions to Support Integrated Silvicultural Prescriptions for Timber and Wildlife: Snags and Old Growth

Martin G. Raphael
U.S. Forest Service
Pacific Northwest
Research Station
Olympia, Washington

Steven L. Marquardt
U.S. Forest Service
Rocky Mountain Region
Delta, Colorado

Reginald H. Barrett
University of California
Berkeley, California

ACKNOWLEDGMENTS

These studies were supported by the Rocky Mountain Forest and Range Experiment Station, the Pacific Northwest Research Station, the Pacific Southwest Forest and Range Experiment Station, the Pacific Southwest Region, and the Rocky Mountain Region of the USDA Forest Service. We thank R.S. Matroni and M.H. Huff for helpful review of an earlier draft, and Janet Jones for administrative assistance.

SUMMARY

Evaluating stand conditions is central to developing management recommendations for maintaining high quality wildlife habitat in forested ecosystems. A stand is defined as a spatially continuous group of trees and associated vegetation having similar structures and growing under similar soil and climatic conditions (Oliver and Larson 1990:1). Stand-level analyses of habitat quality form the basis, for example, of the U.S. Forest Service's Wildlife Habitat Relationships program (Thomas 1979). Under this program, managers develop models that relate species to habitat conditions, with a goal of making inferences from habitat data to ecological carrying capacity of populations. Inferences range from predicting presence of a species to predicting long-term population viability. Stand-level analyses are but one step in a hierarchical series of analyses, and are most useful for predicting presence of wildlife species. More sophisticated predictions, such as relative abundance, require larger-scale, multistand analyses. Predictions at still higher levels, such as of population viability, are usually only possible over a broader scale and must include time as an additional dimension. At larger scales such as drainages, watersheds, or landscapes, stands are the basic building blocks. Thus, stand structure is an important consideration for all levels of analysis. Individual timber stands are also the primary units of forest management. Inventory data and silvicultural treatments, for example, are keyed to individual stands.

In this paper we discuss two important and related attributes of stands: composition and structural characteristics of old-growth stands; and snag abundances, structure, and decay characteristics. We describe a numerical rating system for classifying old-growth stands. This system, an old-growth scorecard, provides an index of old-growth conditions. Scorecard values can range from 0 (no old-growth conditions present) to 60 (maximum attainment of old-growth conditions). The value for any stand is calculated by summing the subscores from each of 12 separate stand attributes. Two of these attributes are the average diameter and density of snags. Because of the importance of snags as wildlife habitat, we include a discussion of new tools to predict the characteristics of snag populations over time.

TABLE OF CONTENTS

ACKNOWLEDGMENTS	2
SUMMARY	2
1 OLD-GROWTH SCORECARD	4
1.1 Background	4
1.2 Approach	5
1.3 Office Preparation	5
1.4 Field Inventory	5
1.5 Assignment of Scorecard Ratings: A Rocky Mountain Example	6
1.6 Validation	8
1.7 Improvements	8
2 SNAG DYNAMICS	10
3 SUMMARY	14
APPENDIX 1. Summary of old-growth stand characteristics identified through available literature	15
APPENDIX 2. Sample scorecard for a stand on the Medicine Bow National Forest, Wyoming	17
REFERENCES	19

FIGURES

1. Mean abundance of small mammal species in relation to old-growth scorecard values, where larger values indicate greater expression of old-growth conditions	9
2. Simulated density of snags over 20 iterations (5-yr intervals) in five decay classes, derived from data in Table 1	10
3. Snag density over time	13
4. Results of sensitivity analysis of snag model components, illustrated for total density of pine snags	14

TABLES

1. Sample input data for snag population model (after Raphael and Morrison 1987)	12
--	----

1 OLD-GROWTH SCORECARD

1.1 Background

Management of old-growth forests requires a classification and inventory of stands meeting old-growth criteria, such as that developed by Franklin *et al.* (1981) for forests of the Pacific Northwest. To date, most classification efforts have required categorizing a stand as either old growth or not old growth. This has led to controversy over which elements to include in a definition of old-growth stands, and estimates of amounts of remaining old-growth forest vary widely depending on definitions used. For example, Morrison (1988) estimated amounts of old-growth forest remaining on six National Forests in Oregon and Washington. He contrasted his estimates, derived from definitions of old-growth forest developed by the Old-growth Definition Task Group (1986), with U.S. Forest Service estimates, obtained by personnel on each National Forest where differing definitions were used. Morrison estimated 0.44 million ha of old-growth forest compared to 1.01 million ha estimated by the Forest Service. This discrepancy resulted from each party using differing criteria to classify old-growth stands.

However, stand attributes vary along a continuum; it is more realistic to recognize that particular stands possess old-growth attributes to varying degrees (Raphael 1988; Franklin and Spies 1991). Therefore, rather than classifying a stand as old growth or not, we suggest an alternative of assigning a stand a numerical rating or index based on the degree to which each attribute is expressed. One such index has been used successfully by the Rocky Mountain Region of the U.S. Forest Service. The Medicine Bow National Forest's old-growth scorecard was originally developed by forest biologists. During the period 1981 through 1984, Forest personnel were heavily involved in preparing the Land and Resource Management Plan. During the initial phase of plan preparation, the Forest received uniform Management Area Prescriptions which specified direction, standards, and guidelines from the Regional Office. One such direction required the forest to provide a minimum of 5% of a unit (generally a fourth-order watershed from 2000 to 10000 ha) in old growth. The intent of this direction was to provide the ecological characteristics in a forested stand to meet the needs of old-growth dependent wildlife species. The Forest Service, recognizing the growing concern surrounding old-growth timber management, began research on the habitat requirements of the old-growth dependent species. This included evaluating stand characteristics, acres needed within a typical diversity unit, amount of contiguous acres, and implications of retaining these stands from the suitable timber base. One result was a change in direction from managing for a minimum of 5% in old growth to a minimum of 10%, with larger percentages in wildlife emphasis areas. A stand size minimum of 12 ha and list of preferred vegetative community types were also identified.

To map stands of suitable timber, it was necessary to identify which stands were unsuitable for harvest. It was decided that stands to be managed as old growth would not be included in the suitable timber base, based on recommendations from a Society of American Foresters Task Force that concluded, "The best way to manage for old growth, according to current knowledge, is to leave it alone" (Heinrichs 1983). Therefore, within the forest's forest-cover database, the Resource Information System (RIS), the Forest Service established a category for old-growth stands and considered the old-growth component as unsuitable for timber harvest.

Stand age taken from the Timber Stand Inventory database was initially used to identify stands for old-growth management because it was the most accurate attribute available to give any indication of the stands' old-growth potential. However, field verification of some stands that were identified as having a high potential for old-growth dependent species indicated that those characteristics important to old-growth species were not present in even some of the oldest aged stands (e.g., 120- to 150-year-old stagnated, densely stocked lodgepole pine with small (DBH). Therefore, to obtain a suitable timber base map to establish an annual allowable sale quantity (ASQ) and identify stands to be managed for old-growth dependent species to meet Forest Plan direction, the Forest Service found it necessary to obtain additional information on the forested stands to identify their old-growth potential.

Forest Service personnel first conducted a literature search to determine which stand characteristics were used by old-growth associated species. The stand characteristics identified were trees with large diameters, presence of long-lived tree species such as spruce and fir, multistoried stand structure, multiple

tree species, dense canopies, presence of dead wood on forest floor, and presence of snags in a range of decay states (Appendix 1). As mentioned, even though timber stand inventory data do exist, these data are inadequate in terms of assessing values for the basic old-growth elements listed above. The scorecard was developed to fill these information gaps.

1.2 Approach

The approach taken by the Medicine Bow National Forest involved a visual estimation of attributes rather than measurement of characteristics from cruised field plots. This approach was chosen because little time was available and results were needed for most stands in the forest. A cruised-plot approach would have yielded more precise information, but fewer stands could have been sampled for the same cost and time. On forests where existing cruise-based inventory data included an adequate assessment of old-growth attributes, index values could be derived from this information. Alternatively, if inventory data are scheduled to be updated, new information could be collected to fill gaps. However, when existing inventories lack crucial attributes and new inventories are not planned, visually estimated data may be a viable alternative.

To assess these elements on the ground adequately, 12 items (Appendix 2) were developed that, if all were present in sufficient quantity and quality, would provide the necessary habitat for the old-growth associated species present in the region. It was recognized that different stands would exhibit varying habitat capabilities as defined by degree of expression of stand attributes. The scorecard value for a particular stand reflected the sum of its scores over the 12 items. The score could range from 0 to 60 (Appendix 2).

The Rocky Mountain Region found, through contracting or doing the work in-house with seasonal technicians, that the most efficient method of rating a particular compartment involved two major steps: office preparation and the actual field inventories. In-house ratings were accomplished at an average (1984) cost of \$6.40/ha.

1.3 Office Preparation

Good office preparation was critical to completing old-growth inventories in the most efficient and economical manner. Some key points included:

- prioritizing inventory areas according to need for the information;
- planning to inventory an entire diversity unit (or drainage or fourth-order watershed), as Forest Plan direction for old-growth management is by diversity unit;
- using the base maps and delineating areas to be field inventoried by location and site or comparable database boundaries, generally by vegetative community type and structural stage;
- using current aerial photos and timber stand inventory data to eliminate stands that exhibited no potential to provide old-growth habitat (e.g., a recent clearcut or a meadow); and
- filling out the heading of the scorecard for each stand or site to be inventoried with one sheet or scorecard for each site.

1.4 Field Inventory

Scores for each item were generally derived from visual estimates of quantity and quality of old-growth components made while the examiner walked through the stand. Each item was rated on the average condition exhibited by the stand as a whole. The examiner also determined extent of stand coverage required to adequately assess overall stand condition.

Some stands exhibited variable conditions. If differences were significant and could be readily defined, the examiner delineated recommended changes on photos and maps while in the field and completed scorecards for each division. If the decision was made to change the boundary lines, a number would be assigned to newly created stands during the evaluation phase. If differences were not well defined, scores were based on the average condition over the majority of the stand. Any additional explanation could be made on the back page of the scorecard under "Remarks."

Throughout the scorecard, only those tree species that constituted 10% or more of the total stems per acre were rated. Shrubs and herbs were excluded from consideration for stand ratings. Tree species that made up less than 10% of the total stems were noted on the back page under item "E."

1.5 Assignment of Scorecard Ratings: A Rocky Mountain Example

The following descriptions show how specific ratings were assigned on the Medicine Bow National Forest. Letters refer to items on the sample scorecard (Appendix 1). Items A through L represent 12 different stand attributes. Each item is assigned a score from 0 (attribute not present) to 5 (maximum attainment).

I. Items A, B, and C are described as follows:

- A. Overstory - trees that form the uppermost canopy layer. In a multistoried canopy, trees with tops that fall within the upper 70–100% of the total stand height are counted as overstory.
- B. Midstory - trees with tops that fall within 30–70% of the total stand height.
- C. Understory - trees with tops that reach from 0 to 30% of the total stand height.

Again, midstory and understory levels must contain at least 10% or more of the total stems per acre to be rated. For items A through C, it may be desirable to record abbreviations for species that occur in each story according to order of abundance —

Example: A. Overstory LP F A

B. Midstory F A

C. Understory F A

LP = Lodgepole pine, F = Fir, A = Aspen

— or this information can be included in the "Remarks" section.

II. Items D, E, and F

Total canopy cover is a measure of the percent of potential open space occupied by the collective tree crowns in the overstory, midstory, and understory of a stand (Thomas 1979:471).

The observer must visually separate the crowns making up the overstory and midstory when rating items E and F.

III. Items G and H

DBH - diameter of a tree at breast height (1.35 m above ground on an uphill side).

With items pertaining to DBH's, training is facilitated by use of diameter tapes during initial phases.

Again, observers should visually separate midstory and overstory when averaging diameters.

IV. Items I and J

For scorecard purposes, a standing snag is defined as any dead, or partly dead, standing tree at least 1.8 m in height with a DBH of 17.5 cm or greater. A partly dead tree is one with a crown that is at least 50% dead.

V. Items K and L

A dead or down log is described in the scorecard as woody material that is dead and lying on the forest floor with a minimum length of 1.8 m and at least 17.5 cm in diameter.

VI. Back Page

- A. Ratings may be grouped into categories according to stands with similar potential. This helps to simplify and organize the data.
- B. Items 1 through 6 on the back page of the scorecard were not included in the numerical rating. They provided additional information that helped examiners make management decisions concerning the stand.

1. Average sight distance - provides a measure of vegetation density and big game hiding cover. Estimate the average distance in feet necessary to hide 90% of a standing adult elk from a human observer.
2. Presence of water - includes springs, seeps, lakes, ponds, and streams.

Perennial water - year-long
Intermittent water - seasonal

3. General stand condition

DECADENT

- heavy accumulations of dead and down material on forest floor
- few large old live trees remaining in overstory (avg. DBH >22.5 cm)
- abundant large snags
- canopy contains all stages of replacement trees
- orange-colored bark

LATE OLD GROWTH

- many healthy live trees (avg. DBH >22.5 cm)
- also many snags and broken tops
- patchy overstory canopy (opening interspersed with dense patches)
- some dead and down; accumulations in spots
- orange-colored bark

EARLY OLD GROWTH

- large proportion of trees are healthy and live (avg. DBH >22.5 cm)
- few snags
- few dead and down of recent origin
- canopy generally intact, few openings
- bark beginning to turn orange

MATURE SAWTIMBER

- almost all trees are live and healthy (avg. DBH >17.5 cm)
- virtually no snags
- no recent dead and down
- gray bark

POLE TIMBER OR OTHER

- trees with average DBH <17.5 cm

4. Self-explanatory
5. Record information about tree species that constitute less than 10% of the total trees per acre. These trees are excluded from rating as they are not typical of the stand.
6. Remarks/recommendations
Priority items recognized in this section include:
 - wildlife observations and wildlife sign; note particularly the presence of cavity-dependent species and evidence of use (e.g., nests, excavated holes in trees, roosting)

- stand characteristics not recorded on front page of scorecard, such as mistletoe infection, understory suppression, abundance of spike tops, state of decay for standing snags and dead and down logs, variations in the stand that are lost in the averaging, and spatial arrangement of trees — clump, patchy, uniform, concentrations of snags or dead and down
- dominant condition of stands adjacent to the inventoried stand
- indicators of previous use or past history of the stand (e.g., timber sale, tie-hacking, burn)
- ground vegetation

1.6 Validation

Raphael (1987, 1988) evaluated the efficacy of the scorecard system to assess strength of association of small mammals and old-growth conditions. For these studies, 180 sampling stations were assigned an old-growth score (as determined by National Forest personnel) for the stand in which they were located. Based on an ongoing trapping program, capture rates of nine mammalian species were computed at each station. Mean capture rates were then compared among five classes of scorecard values (Appendix 1). Results (Figure 1) were in accordance with expected trends based on available literature (Raphael 1988). For example, the southern red-backed vole, listed as a management indicator species for old-growth conditions, showed trends of increasing abundance with increasing old-growth scores. The deer mouse, a ubiquitous species that thrives in disturbed habitats, showed a significant declining trend. Raphael (1988) concluded that the scorecard values were useful in characterizing habitat for small mammals. Other studies (M.G. Raphael, unpublished data) support the usefulness of this approach for birds.

1.7 Improvements

This approach has proven its usefulness as applied on the Medicine Bow National Forest. Application to other geographic areas most likely will require adjustments or deletion of some attributes, and the addition of others. For example, to apply this to westside forests of the Cascades of Washington and Oregon would require new tree species designations and different canopy layer categories. New attributes may also be helpful. Information on lichens, decay organisms, stand patchiness, and understory composition could improve scorecard usefulness.

Stand size and shape are additional considerations that might be included in computing index values. Many National Forests use a minimum area of 4 ha to classify stands as old growth; stands less than 4 ha are not included in old-growth inventories. In a scorecard, this could easily be added using a multiplier for stand size, where stands >4 ha are assigned a "1" and smaller stands a "0." Multiplying would give small stands a summary value of "0." A finer-grained approach would involve additional categories (higher point values for larger stand-size categories) and would be additive. Stand shape is important because large narrow stands may not have the same habitat value as large round stands, especially if edge contrast is great, as in stands surrounded by recently cut forest. Stand shape indices such as Patton's index (Patton 1975) or fractal dimension (O'Neill *et al.* 1988) could be coded as additional attributes.

The old-growth scorecard has been applied on all suitable stands on the Medicine Bow National Forest. It has also been applied, to a more limited extent, on at least five other national forests in the Rocky Mountain region. In summary, the scorecard is not intended to account for all the variation possible in old-growth stands. It provides a method for evaluating the old-growth value of a stand, as well as a means for comparing stands in order to make resource management decisions.

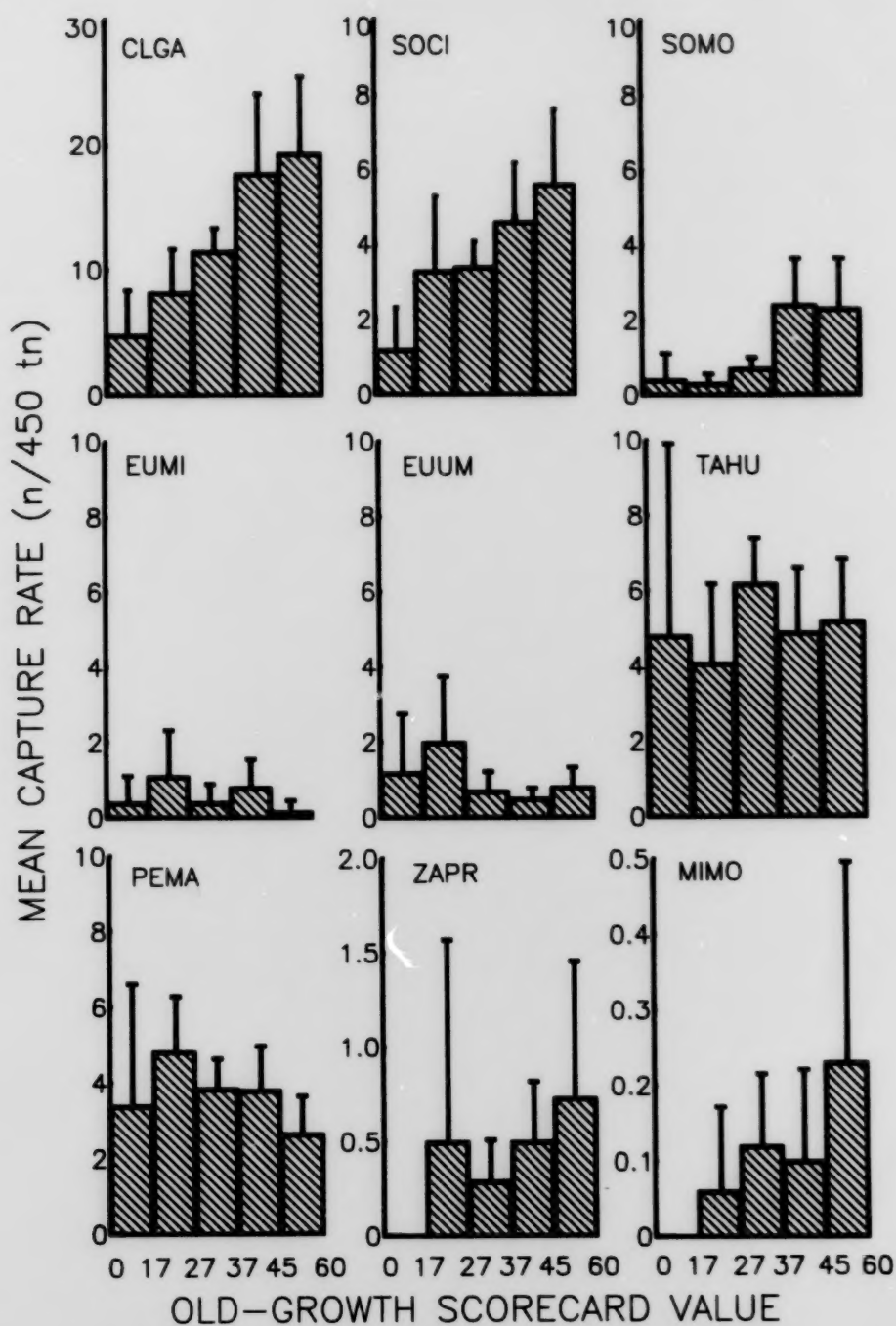


FIGURE 1. Mean abundance of small mammal species in relation to old-growth scorecard values, where larger values indicate greater expression of old-growth conditions. Species codes are CLGA, *Clethrionomys gapperi*; SOCI, *Sorex cinereus*; SOMO, *Sorex monticolus*; EUMI, *Eutamias minimus*; EUUM, *Eutamias umbrinus*; TAHU, *Tamiasciurus hudsonicus*; PEMA, *Peromyscus maniculatus*; ZAPR, *Zapus princeps*; MIMO, *Microtus montanus*. Capture rate is expressed as number of captures per 450 trapnights; vertical bars indicate 95% confidence intervals.

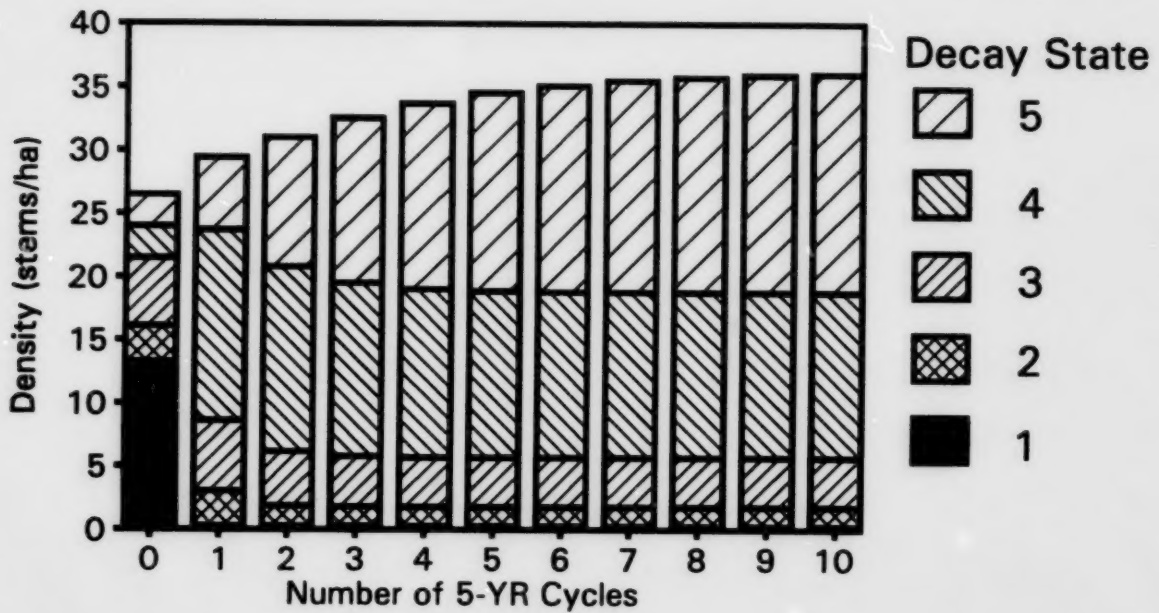


FIGURE 2. Simulated density of snags over 20 iterations (5-yr intervals) in five decay classes, derived from data in Table 1.

2 SNAG DYNAMICS

One of the critical attributes of old-growth stands is the abundance of snags, or standing dead trees. Snag populations are dynamic, changing in number as they fall or are recruited through live-tree mortality, and changing in size and texture as they decay. Among the many attributes of old-growth and other stands, snag populations may be the most variable over time. Therefore, we include a simple model to demonstrate an approach for tracking changing snag numbers and decay characteristics over time. But first, why are managers so concerned about snags?

More than 50 years ago, Grinnell and Storer (1924) decried the even-then common practice of cutting down dead trees during harvest and other forest management operations. They recommended leaving dead trees for the breeding, food, and shelter needs of wildlife. These dead trees, or snags, are an important habitat element for many forest wildlife species, and a *sine qua non* feature for important species such as woodpeckers. Without snags, they cannot exist.

Wildlife species regularly use snags for a variety of purposes, including nesting, feeding, and shelter, as well as for observation and communication. The success and abundance of many wildlife populations depend upon numerous snags being present and distributed over the landscape. Cavities and crevices in snags provide shelter from predators and inclement weather, and sites for sleeping, resting, nesting, and rearing young. Snags produce a rich source of foods, in addition to providing observation points from which wildlife, particularly birds, feed out into surrounding areas. Many species also use snags as singing, calling, and drumming sites.

Increasing demand for forest products and the increasing use of forest lands create problems of multiple-use policy and regulation. The snag exemplifies these problems, as timber harvest, other management activities, and recreational uses increase. Snags can be used for lumber, pulp, or energy. Their use as a heating substitute for fossil fuels has increased so much that in some areas snags are disappearing from roadsides and other accessible areas. Snags also may be a safety or fire hazard in certain areas.

In California, the State Board of Forestry sponsored a committee investigation of the needs of wildlife for snags. In response to the recommendations of this committee (Study Committee on Snags 1976), the Board removed long-standing regulations requiring felling of most snags during timber operations. Retaining snags for wildlife is now encouraged in California, except where specific reasons of safety or fire hazard require removal of individual snags.

On federally managed lands in the United States, guidelines and standards for snag management are set forth in land management plans as mandated by the *National Forest Management Act* of 1976. These usually call for the maintenance of minimum numbers of snags per unit area that meet certain size and species specifications. For example, in the Medicine Bow National Forest of Wyoming, the Land Management Plan calls for maintaining an average of 20–30 snags >30 cm DBH per 4.04 ha in subalpine habitats.

Minimum snag density requirements have been estimated for several geographic regions including eastern Oregon and Washington (Thomas 1979), and western Oregon and Washington (Brown 1985). These guidelines are static. Although they provide managers with a management objective (numbers of snags per acre), they do not recognize the dynamic properties of snag populations. Numbers and characteristics of snags change over time. Individual snags decay with age, progressively losing needles, fine branches, larger branches, bark, and top. Populations change as standing snags fall and new snags are recruited when live trees die. Rates of decay and population dynamics vary with size and species of tree. All of this means that managers must consider the changing numbers and characteristics of snags over time.

Snag populations are dynamic — numbers and characteristics change over time. Therefore, meeting standards and guidelines for snags is difficult. A one-time inventory is not sufficient to assure meeting habitat objectives. One solution is frequent monitoring, perhaps as often as every 5 years. But this is expensive unless snag monitoring can be “piggy-backed” into other ongoing activities. Instead, we suggest using models to estimate changes in snag populations, supplemented by periodic monitoring (perhaps every 10 years) to validate model predictions.

Several modeling approaches have been suggested. Cimon (1983) derived a simple equation to predict numbers of standing snags of a given species by diameter class:

$$S_d(n+1) = (S_d(n) \times P_d) + (T_d(n) \times M)$$

where $S_d(n)$ is the number of snags of diameter class d at the start of time interval n , P_d is the probability that a snag of diameter d will remain standing during the time interval, $T_d(n)$ is the number of live trees of diameter d , and M_d is the probability that a live tree of diameter d will die during one time interval. Although simple to use, this model fails to account for snag decay.

Marcot (1988) developed the Snag Recruitment Simulator (SRS), a spreadsheet model that calculates numbers of snags by DBH and decay class over time for even-aged Douglas-fir forest, based on data in Neitro *et al.* (1985) and Curtis *et al.* (1981). The SRS is designed to run on a personal computer using Lotus 1-2-3 or similar spreadsheet programs. It contains data on decay rates and falling rates of snags by DBH class. It also contains snag recruitment information. The model uses a life-table approach to calculate how many snags will fall, how many will be added, and how many will occur in each class over 10-year increments.

Raphael and Morrison (1987) developed a similar snag population model using a Leslie matrix approach. Their model accounts for transitions of snags from one decay stage to the next, snag falling rates, and snag recruitment. The model can be adapted to any desired tree species or diameter class by changing matrix values (see below).

Model structure is quite simple. It has the form:

$$N_{t+1} = D N_t + R$$

where D is a table (matrix) of transition probabilities that a snag will decay from one stage to the next during time t , N_t is the density of snags in each decay stage at time t , and R is the density of new snags recruited into the population during time t . Calculations are repeated over any desired number of repetitions. If, for example, one wished to estimate populations over 100 years, and data were derived for a time interval of 4 years, calculations would be repeated $100/5 = 20$ times.

We have adapted the Raphael-Morrison model for use with Lotus 1-2-3 on a personal computer. This version, available from the senior author on request, is fast and easy to use. The user simply adjusts values in the input table (Table 1) to reflect local conditions, then presses one button to display trends of snag numbers in each of five decay classes over ten 5-year intervals (Figure 1). Figure 3 shows how numbers of snags in each decay class might change over time under different management objectives.

We conducted a sensitivity analysis to evaluate changes in snag population dynamics with respect to each input variable or cell (N , D , R) using a Lotus 1-2-3 add-on program (Impact Solutions, Enfin Software Corp., 6920 Miramar Rd., Suite 106A, San Diego, CA 92121). This analysis showed that survival rates of class 4 and 5 snags were the most sensitive variables (Figure 4). A 10% change in transition probabilities of these decay classes resulted in 35-55% changes in total density of snags. Varying initial estimates of all other variables resulted in impacts of <10%. Therefore, managers may need to put special emphasis on monitoring survival of class 4 and 5 snags.

TABLE 1. Sample input data for snag population model (after Raphael and Morrison 1987). These values apply to pine snags in a Sierra Nevada forest

Decay stage at $t + 1$	Stage-specific survival rate/5 yr (D)					Number/ha	
	Decay at time t					Initial density (N)	Recruits (R)
	1	2	3	4	5		
1	0.00	0.00	0.00	0.00	0.00	13.30	0.28
2	0.09	0.06	0.00	0.00	0.00	2.80	1.42
3	0.10	0.13	0.14	0.00	0.00	5.40	3.13
4	0.36	0.27	0.30	0.33	0.00	2.50	7.11
5	0.05	0.02	0.02	0.24	0.67	2.50	2.27
Standing	0.60	0.48	0.52	0.57	0.67	25.60	14.21
Falling	0.40	0.52	0.48	0.43	0.33		

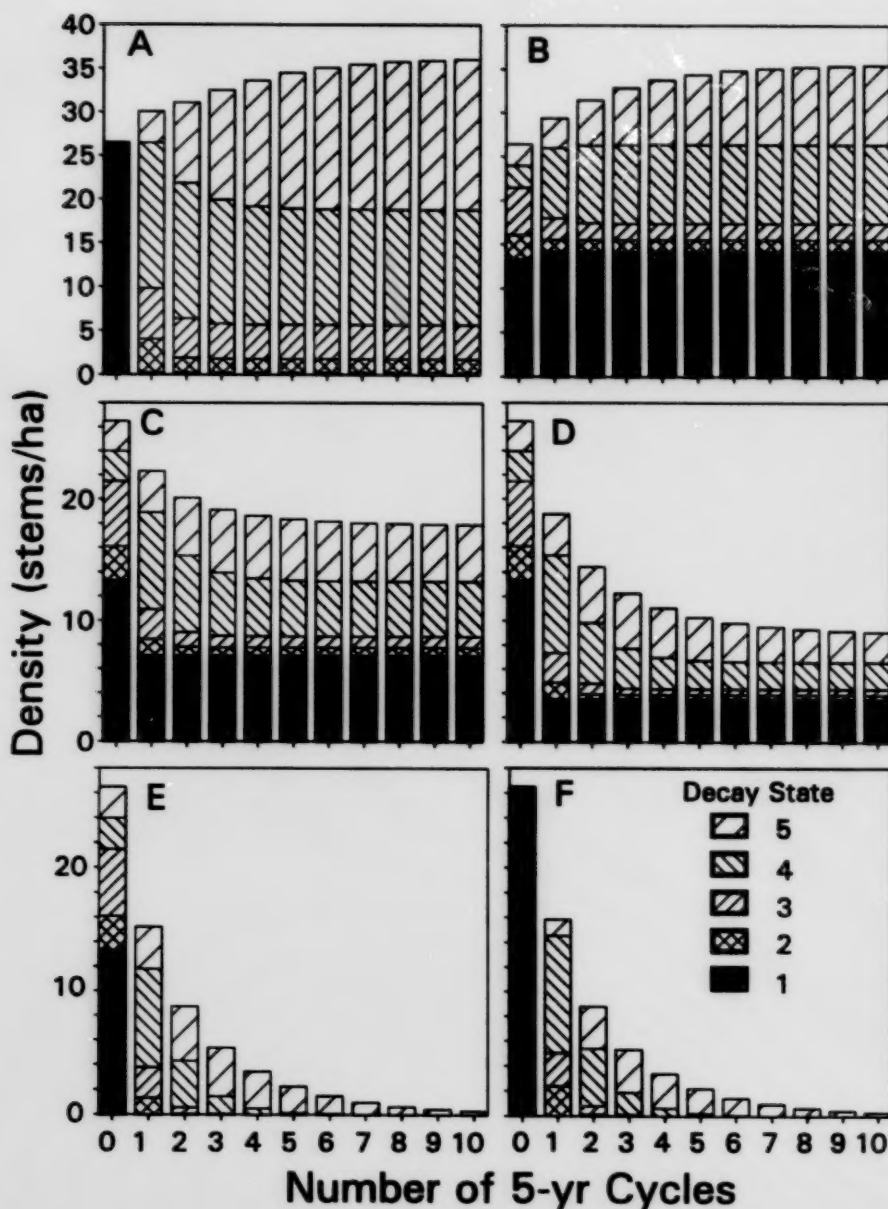


FIGURE 3. A. Snag density over time as in Figure 2, modified so that starting density equalled 36.1 snags, all in decay class 1. Note that, after the first iteration, results are identical to those from Figure 2. B. Snag density over time as in Figure 2, modified so that recruitment equalled 14.2 snags/ha per 5 yrs, all in decay class 1 (hardest). C. Snag density over time, as in Figure 2, modified so that recruitment equalled 7.1 decay class 1 snags/ha per 5 yrs. D. Snag density over time as in Figure 2, modified so that recruitment equalled 3.5 decay class 1 snags/ha per 5 yrs. E. Snag density over time as in Figure 2, modified so that total recruitment equalled zero. F. Snag density over time, assuming no recruitment and a starting density of 26.1 decay class 1 snags/ha. This simulates a likely situation following fire.

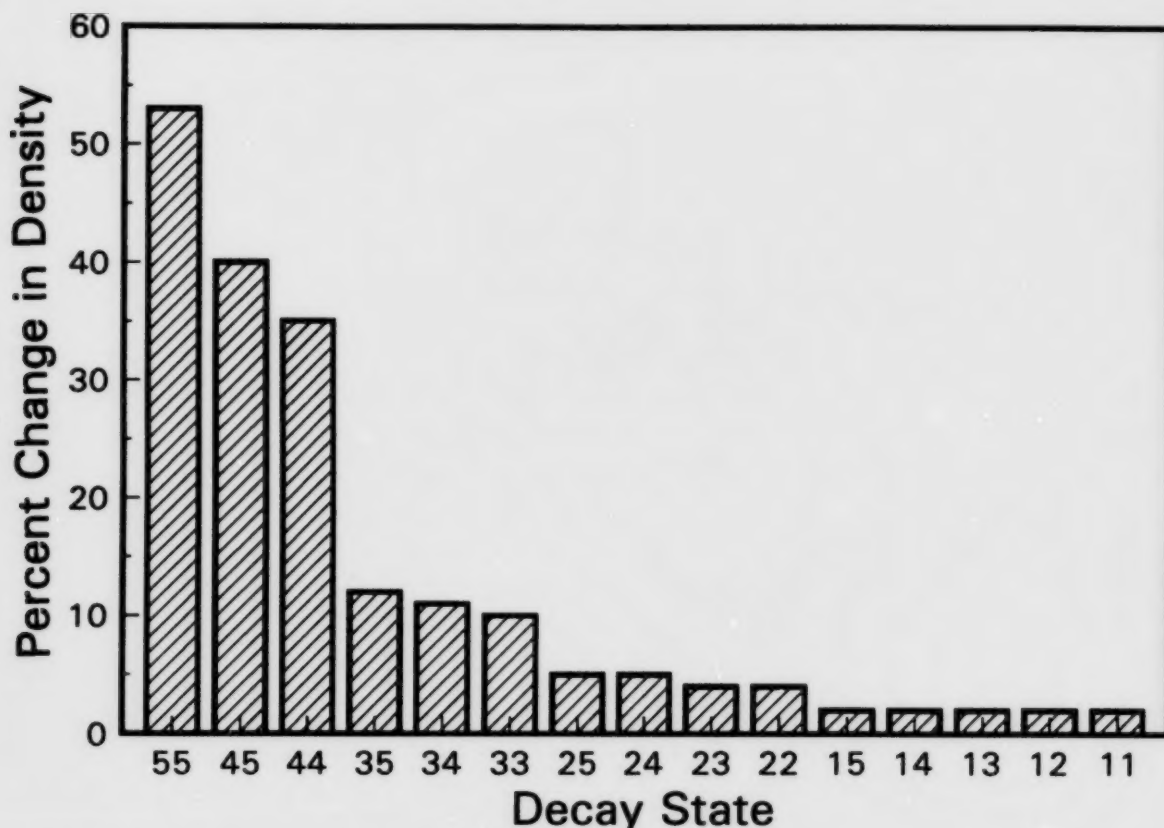


FIGURE 4. Results of sensitivity analysis of snag model components, illustrated for total density of pine snags. Height of bars indicates percent change in total density; individual bars are model components (e.g., 45 is transition rate of decay class 4 to decay class 5 snags).

3 SUMMARY

We have described two tools that may be useful to forest managers. The first, an old-growth scorecard, provides a method of assigning a numerical rating to a stand. This rating is a composite summary of the degree to which that stand possesses each of 12 attributes that are important aspects of old-growth forest condition. The rating incorporates estimates of canopy cover in three canopy layers, diameter of overstory trees, diameter and density of snags, and diameter and density of logs. The advantage of this rating system is that it places old-growth condition along a continuous scale from 0 (no old growth) to 60 (maximum old growth) rather than as a simple dichotomy — the stand *is* old growth or it *is not* old growth. Stands can always be grouped into fewer categories defined by a range of scorecard values (e.g., 0–15, 16–30, 31–45, 46–60). We believe this approach is very useful in relating old-growth condition to wildlife habitat value. We recognize, however, that a variety of attribute scores can add to the same overall rating.

Our second tool focused on one attribute of stand condition, snags. Snag populations are dynamic — density and decay condition change over time. We have illustrated a Leslie-matrix model that predicts the number of snags in five decay classes over time, based on initial density and recruitment rate. This model provides managers with a powerful tool to anticipate changing snag populations and this, in turn, allows prediction of the responses of cavity-nesting wildlife. The model is simple and easy to use. If tied to wildlife population models, results can be used to develop acceptable snag management objectives.

APPENDIX 1. Summary of old-growth stand characteristics identified through available literature

1. Trees with large diameters. Juday 1978; Wellersdick and Zalunardo 1978; Bull *et al.* 1980; Marcot 1980; USDA Forest Service 1980; Meslow *et al.* 1982; Heinrichs 1983.

Specific comments:

Large snags have two advantages: greater number of cavity-dependent species can use them and the snag will stand longer. (Bull *et al.* 1980:326)

Large snags and logs retain moisture longer than small ones and therefore provide a better habitat for insect larvae. (Wellersdick and Zalunardo 1978:26)

Larger snags can be used by cavity-nesting species with smaller diameter requirements, but the reverse is not true. (Thomas *et al.* 1979:70)

2. Emphasis on spruce and fir species, which are long-lived species.

Spruce trees seemed to be preferred by cavity nesters in a study comparing cavity nesting in lodgepole pine, subalpine fir and Engelmann spruce. (Scott *et al.* 1980:316)

Lodgepole old growth often lacks large trees, and stands tend to break apart and deteriorate much faster than do old-growth Douglas-fir stands. (Heinrichs 1983:777)

Long-lived species are more valuable in an old-growth system than species that do not attain comparable sizes or persist as long when dead. (Heinrichs 1983:779)

3. Multistoried stand structure. (Mannan 1980; Marcot 1980; Meslow *et al.* 1982; Heinrichs 1983)

Specific comments:

The structural complexity, great vertical development and horizontal patchiness of old-growth forests allow a relatively high number of wildlife species and individuals to exist there. (Meslow *et al.* 1982:330)

"Old growth forest stands are structurally complex with great vertical development and considerable intra-stand variability." (Meslow 1982:330)

4. Multiple species. (Maser *et al.* 1979; Heinrichs 1983)

Specific comments:

"...a manager has a greater number of alternatives in meeting log requirements for wildlife habitat in an uneven aged, mixed species stand. Mixed species provide varying degrees of decay resistance and a variety of potential stem diameters." (Maser *et al.* 1979:94)

The old-growth task force (Society of American Foresters) identified the existence of two or more tree species as one of the desirable components composing an average acre of old growth. A long-lived seral dominant is often found in association with a shade-tolerant species. (Heinrichs 1983:776)

5. Dense canopies. (Maser *et al.* 1979; Thomas 1979; Marcot 1980; Heinrichs 1983)

Specific comments:

Mesic microhabitats afforded by high canopy closure are among the components of "old growth" that may be important to wildlife species. (Marcot 1980:393)

Koehler *et al.* (1975) reported that pine marten and their preferred prey species favor mesic conifer stands in Idaho.

6. The presence of dead and down woody material on the forest floor. (Wellersdick and Zalunardo 1978; Marcot 1980; Meslow *et al.* 1982; Heinrichs 1983)

Management plan for dead and defective trees on the Olympic National Forest (Juday 1978; USDA Forest Service 1980)

Specific comments:

Fallen woody debris has important ecological implications in terms of mineral cycling, nutrient immobilization, nitrogen fixation, fire and wildlife habitat. (Maser *et al.* 1979:79)

The presence or absence of down logs may influence the selection of nest sites by cavity-nesting species. Down logs provide an important food source for woodpeckers. (Wellersdick and Zalunardo 1978:28)

"Wildlife use fallen logs as lookout perches, escape cover, runways and travel routes, and food sources." (Juday 1978:504)

7. The presence of standing snags with decayed wood. (Wellersdick and Zalunardo 1978; Marcot 1980)

Management plan for dead and defective trees on the Olympic National Forest (USDA Forest Service 1980). (Juday 1978; Thomas *et al.* 1979; Bull *et al.* 1980; Mannan *et al.* 1980; Meslow *et al.* 1980; Scott *et al.* 1980; Heinrichs 1983)

Specific comments:

"...[D]ying and dead wood provides one of the two or three greatest resources for animal species in a natural forest....[I]f fallen timber and decayed trees are removed the whole system is gravely impoverished, of perhaps more than a fifth of its fauna." (Maser *et al.* 1979:78)

Nesting in cavities is a very successful breeding strategy, since adults, eggs and nestlings as well as roosting animals are protected from the elements and predators. (Wellersdick and Zalunardo 1978:1)

APPENDIX 2. Sample scorecard for a stand on the Medicine Bow National Forest, Wyoming. For each attribute (A through L), points are assigned based on the most appropriate level for that attribute. For example, a stand with 60% canopy cover would receive 4 points for attribute D.

Timber Type	Compartment	Stand	Date
District	¼ Section + Sec.	RIS Site	Examiner
Forest	Township & Range	Numeric Rating	Old-Growth Condition
Attribute Score			
5	4	3	2
1			
A. Overstory LP, SF 3 or more species Spruce and/or Fir >50% 3 or more species Spruce and/or Fir <50% 2 species Spruce and/or Fir >50% 2 species Spruce and/or Fir <50% 1 species 100%			
A. Midstory LP, SF 3 or more species Spruce and/or Fir >50% 3 or more species Spruce and/or Fir <50% 2 species Spruce and/or Fir >50% 2 species Spruce and/or Fir <50% 1 species 100%			
A. Understory LP, SF 3 or more species Spruce and/or Fir >50% 3 or more species Spruce and/or Fir <50% 2 species Spruce and/or Fir >50% 2 species Spruce and/or Fir <50% 1 species 100%			
D. Total Canopy Cover 70% + 70-50% 50-30% 30-10% <10%			
E. Overstory, Canopy Cover 50-30% 70-50% or 30-10% 100-70% or 10-1%			
F. Midstory Canopy Cover 40-20% 70-40% or 20-10% 100-70% or 10-1%			
G. Overstory Ave. DBH (cm, Live) >38 38-33 32-25 24-18 <18			
H. Midstory Ave. DBH (cm, Live) >23 23-15 14-8 <8			
I. Standing Snags Ave. DBH (cm; Record only those snags above 2 m height) >38 38-33 32-25 24-18 <18			
J. Standing Snags #/ha (Record only those snags above 2 m height and 18 cm DBH) >17 17-10 9-1			
K. Dead, Down Logs Ave. Diameter (cm) >38 38-33 32-25 24-18			
L. Dead, Down Logs #/ha (Record only those above 18 cm Diameter) 12+ 11-6 5-2			
Column Totals*			

* Column total is the sum of all values for that column. The sum of these totals is the overall scorecard value, and is entered as "numeric rating" above.

APPENDIX 2. (Cont'd.)

Example of reverse side of scorecard where ancillary information is noted:

Rating Value	
Numeric	Old-Growth Condition
46-60	High
38-45	Moderate
28-37	Low
18-27	Some Potential
0-17	Very Little Potential

Other Habitat Characteristics that Complement an Old-Growth Stand

Recorded, but not rated

1. Average Sight Distance _____ <125'
 _____ 125'-200'
 _____ 200' +
2. Presence of Water _____ Perennial within Stand
 _____ Intermittent Surface Water Present
 _____ Perennial within 1/4 mile of Stand Boundary
3. General Stand Condition _____ Decadent
 _____ Late Old-Growth Stage
 _____ Early Old-Growth Stage
 _____ Mature Sawtimber
 _____ Other (Seed-Sap, Post-Pole, etc.)
4. Acreage of Stand _____
5. Other tree species that constitute less than 10% of the total trees per acre. (Not rated on Scorecard.)

6. Remarks/Recommendations:

REFERENCES

- Alexander, R.R. 1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: the status of our knowledge. USDA For. Serv. Rocky Mt. For. and Range Exp. Sta., Fort Collins, Col. Res. Pap. RM-121 88 p.
- Brown, E.R. (technical editor). 1985. Management of wildlife and fish habitats in forest of western Oregon and Washington. USDA For. Serv., Pac. NW Region. Publ. R-6-R&WL-192-1985.
- Bull, E.L., A.D. Twombly, and T.M. Quigley. 1980. Perpetuating snags in managed mixed conifer forests of the Blue Mountains, Oregon. *In* Workshop Proc. on Management of Western Forests and Grasslands for Nongame Birds. USDA For. Serv. Gen. Tech. Rep. INT-86, pp. 325-336.
- Cimon, N. 1983. A simple model to predict snag levels in managed forests. *In* Snag habitat management: Proc. Symp. J.W. David, G.A. Goodwin, and R.A. Ockenfels technical coordinators). USDA For. Serv. Gen. Tech. Rep. RM-99.
- Curtis, R.O., G.W. Clendenen, D.L. Reukema, and D.J. Demars. 1981. Yield tables for managed stands of coast Douglas-fir. USDA For. Serv. Gen. Tech. Rep. PNW-135.
- Franklin, J.F., K. Cromack, Jr., W. Densison, A. McKee, C. Maser, J. Sedall, F. Swanson, and G. Juday. 1981. Ecological characteristics of old-growth Douglas-fir forests. USDA For. Serv., Pac. NW Res. Sta. Portland, Ore. Gen. Tech. Rep. PNW-GTR-118. 48 p.
- Franklin, J.F. and T.A. Spies. 1991. Ecological definition of old-growth Douglas-fir forests. *In* Wildlife and vegetation of unmanaged Douglas-fir forests. L.F. Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff (technical coordinators). USDA For. Serv. Pac. NW Res. Sta. Gen. Tech. Rep. PNW-GTR-285, pp. 71-82.
- Grinnell, J. and I. Storer. 1924. Animal life in the Yosemite. Univ. California Press, Berkeley, Cal.
- Heinrichs, J. 1983. Old growth comes of age. *J. For.* Dec. 1983: pp. 776-779.
- Hendzel, L. 1982. Judging riparian ecosystem condition. USDA For. Serv., Rocky Mountain Region. Lakewood, Colo. 80225.
- Juday, G.P. 1978. Old growth forests: a necessary element of multiple use and sustained yield National Forest management. *Environmental Law*. 8: pp. 497-522.
- Koehler, G.M., W.R. Moore, and A.R. Taylor. 1975. Preserving the pine marten: management guidelines for western forests. *W. Wildl.* 2:31-36.
- Mannan, W.R. 1980. Assemblages of bird species in western coniferous old-growth forests. *In* Workshop Proc. on Management of Western Forests and Grasslands for Nongame Birds. USDA For. Serv., Intermountain Region. Gen. Tech. Rep. INT-86, pp. 357-368.
- Marcot, B.G. 1980. Use of habitat/niche model for old growth management: a preliminary discussion. *In* Workshop Proc. on Management of Western Forests and Grasslands for Nongame Birds. USDA For. Serv., Intermountain Region. Gen. Tech. Rep. INT-86, pp. 390-402.
- Maser, C., R.G. Anderson, K. Cromack, Jr., J.T. Williams, and R.E. Martin. 1979. Dead and down woody material. *In* Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. J.W. Thomas (editor). USDA For. Serv. Agric. Handbk. No. 553, pp. 60-77.
- Meslow, E.C., C. Maser, and J. Verner. 1982. Old growth forests as wildlife habitat. *Trans N. Amer. Wild. and Nat. Resources Conf.* 46:329-335.
- Morrison, P.H. 1988. Old growth in the Pacific Northwest: a status report. The Wilderness Society, Washington, D.C. 20005.

- Neitro, W.A., V.W. Binkley, S.P. Cline, R.W. Mannan, B.G. Marcot, D. Taylor, and F.F. Wagner. 1985. Snags (wildlife trees). *In* Management of wildlife and fish habitats in forests of western Oregon and Washington. E.R. Brown, (technical editor) USDA For. Serv., Pac. NW Region, R6-F&WL-192-1985, Chap. 7, pp. 129-169.
- Old-Growth Definition Task Group. 1986. Interim definitions for old-growth Douglas-fir and mixed-conifer forests in the Pacific Northwest and California. USDA For. Serv. Pac. NW Res. Sta. Portland, Ore. Res. Note PNW-RN-447. 7 p.
- Oliver, C.D. and B.C. Larson. 1990. Forest stand dynamics. McGraw-Hill, New York, N.Y.
- O'Neill, R.V., J.R. Krummel, R.H. Gardner, G. Sugihara, B. Jackson, D.L. DeAngelis, B.T. Milne, M.G. Turner, B. Zygmunt, S.W. Christensen, V.H. Dale, and R.L. Graham. 1988. Indices of landscape pattern. *Landscape Ecology* 1:153-166.
- Patton, D.R. 1975. A diversity index for quantifying habitat "edge." *Wildl. Soc. Bull.* 3:171-173.
- Raphael, M.G. 1987. The Coon Creek wildlife project: effects of water yield augmentation on wildlife. *In* Proc. on Management of Subalpine Forests: Building on 50 Years of Research. C.A. Troendle, M.R. Kaufmann, R.H. Hamre, and R.P. Winokur (editors). USDA For. Serv. Gen. Tech. Rep. RM-149, pp. 173-179.
- . 1988. Habitat associations of small mammals in a subalpine forest, Wyoming. *In* Management of amphibians, reptiles, and small mammals in North America. R.D. Szaro, K.E. Severson, and D.R. Patton (technical coordinators). USDA For. Serv. Gen. Tech. Rep. RM-166, pp. 359-367.
- Raphael, M.G. and M.L. Morrison. 1987. Decay and dynamics of snags in the Sierra Nevada, California. *For. Sci.* 33:774-783.
- Scott, V.E., J.A. Whelan, and P. Svoboda. 1980. Cavity nesting birds and forest management. *In* Workshop Proc. on management of western forests and grasslands for nongame birds. USDA For. Serv., Intermountain Region. Gen. Tech. Rep. INT-86, pp. 325-336.
- Study Committee on Snags. 1976. Report for Board of Forestry, California Div., Sacramento, Cal.
- Thomas, J.W., R.G. Anderson, C. Maser, and E.L. Bull. 1979. Snags. *In* Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. J.W. Thomas (editor). USDA For. Serv. Agric. Handbk. No. 553.
- Thomas, J.W. (technical editor). 1979. Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. USDA For. Serv. Agric. Handbk. No. 553.
- USDA Forest Service. 1980. Management plan for dead and effective trees on the Olympic National Forest. Pac. NW Region, Olympic National For.
- Wellersdick, M. and R. Zalunardo. 1978. Characteristics of snags used by wildlife for nesting and feeding in the western Cascades, Oregon. USDA For. Serv., Pac. NW Region, Umpqua National Forest. 31 p.

2



Modeling Forest Landscapes in Support of Integrated Resource Management and Cumulative Effects Analysis

Eddie Morris
USDA Forest Service
508 Oak Street
Gainesville, Georgia

Ben Sanders
USDA Forest Service
508 Oak Street
Gainesville, Georgia

Richard Holthausen
USDA Forest Service
911 NE 11th Avenue
Portland, Oregon

ABSTRACT

The Chattahoochee-Oconee National Forest in northeast Georgia has developed a set of tools to assist land managers in the development and analysis of project alternatives. This set of tools consists of nine computer subroutines in a system entitled IMLEM. The system allows resource managers to store, edit, and retrieve stand-level data; generate a list of forest stands that are candidates for regeneration; develop alternative sets of cultural treatments; and analyze the effects of each alternative in terms of changes in wildlife habitat, sedimentation, timber production, costs, and revenues. The system is being used by interdisciplinary teams to select preferred alternatives for managing the forest at the analysis area level and as a monitoring tool to track compliance with the Forest Land and Resource Management Plan.

TABLE OF CONTENTS

ABSTRACT	22
1 PROBLEM ANALYSIS	24
1.1 The Issue	24
2 HISTORICAL APPROACH TO RESOLVING THE ISSUE	24
3 MANAGEMENT CONTEXT AND ALTERNATIVES	26
4 CASE EXAMPLE OF A TIMBER-HABITAT MANAGEMENT TOOL	27
4.1 Introduction	27
4.2 The CHHABCAP Model	30
4.2.1 Species-habitat relations modeled in CHHABCAP4	30
4.3 CHHABCAP4 Source Listing	31
5 TECHNOLOGY TRANSFER	31
6 EVALUATION	32
7 QUESTIONS TO BE ANSWERED	32
8 SUMMARY	32
APPENDIX A. Sample output from the Candidate Stand program (CAND)	33
APPENDIX B. Sample output from the CompPATS program	34
APPENDIX C. Sample output from the CHHABCAP program	37
APPENDIX D. Fortran source code for the CHHABCAP habitat capability program	38
APPENDIX E. Index to abbreviations used in appendices	57
LITERATURE CITED	59

1 PROBLEM ANALYSIS

1.1 The Issue

Land managers often need to evaluate existing conditions and analyze alternative actions to achieve specified objectives for the land they manage. The traditional sources of information available for this type of analysis include field examinations, aerial photographic information, and satellite imagery. Many managers have been faced with a proliferation of data and a lack of appropriate tools to analyze these data.

Analysis tools have been needed that will facilitate evaluation and analysis at the watershed level, or areas of approximately 10000–15000 acres (4000–6000 ha). The USDA Forest Service has become increasingly involved in the analysis and evaluation of existing conditions and alternatives for management since the passage of the *National Environmental Policy Act* of 1974 and the *National Forest Management Act* of 1976. These acts mandate extensive evaluation of habitat conditions at the project or analysis area level. Projects involve areas of 1000–5000 acres (400–2000 ha). Analysis areas typically involve multiple project areas. The process under the *National Environmental Policy Act* requires detailed documentation of an analysis of alternatives for management decisions. Since management decisions for National Forest lands must consider multiple use objectives, managers need tools to help them determine the resource trade-offs between various alternatives, and the cumulative effects of implementing each alternative.

Knowledge of potential cumulative effects, both in time and space, of proposed actions is crucial to an analysis of alternatives. The manager needs to know the nature and relative magnitude of social, biological, economic, and political consequences of various alternatives before he or she can make an informed decision. This information should be readily available to the manager in a form that clearly displays the relative values and resource effects of each alternative.

2 HISTORICAL APPROACH TO RESOLVING THE ISSUE

Several generations of managers have struggled with the problem of integrating timber and wildlife concerns and information in their decision-making. Their efforts have taken at least four distinct forms: 1) timber management guidelines with no explicit mention of wildlife; 2) guidelines for featured species of wildlife; 3) habitat relationship books and early attempts at home range or area-level analysis; and 4) evolving analytical systems that attempt to truly integrate timber and wildlife information.

The earliest efforts at integration followed the adage that "good timber management is good wildlife management." Guidelines were established for timber management with the expectation that the guidelines would also have positive benefits for wildlife. There was little consideration of the details of species/habitat relationships, and no actual analysis of effects of management schemes on species. Guidelines were generally aimed at forest regeneration needs and considerations of potential for erosion and watershed degradation. Resulting guidelines generally controlled the size of harvest units, the dispersion of units, and the productivity and erosion risk of sites that could be considered for harvest. Such guidelines were common in U.S. Forest Service timber management plans in the 1950's and 1960's. While such notions were crude, they probably were beneficial to large ungulate species in areas where timber harvest produced forage increases and where forage:cover ratios had not become lopsided. These guidelines are still being used as part of the overall set of guidelines for forest management on National Forests. Guidelines for harvest unit size and dispersion were included in the regulations for the *National Forest Management Act* (36 CFR 219). Regional guides produced under this act all contained similar guidelines, and some also considered the proportion of total area that should be retained in specific successional stages of vegetation.

The first attempts to consider wildlife/timber interactions explicitly came in the form of featured species guidelines. Guidelines generally addressed game species, and they were aimed at the silvicultural treat-

ment of individual stands. In some cases, minor consideration was given to patterns among stands. A good example of such guidelines was the Wildlife Habitat Management Handbook produced by the Southern Region of the U.S. Forest Service. This handbook presented information for nine hunted wildlife species. It discussed habitat requirements for each and presented information on the following management considerations: standard management practices, stand size and distribution, rotation, regeneration, conversion, site preparation, intermediate treatments, prescribed burning, and direct improvements. Such guidelines represented a significant advancement in the incorporation of wildlife considerations into timber management. They allowed silviculturists and wildlife biologists to discuss, in a common language, management practices that would be valuable for both wildlife and timber production. They did not, however, allow for specific analysis of effects of management on wildlife and the trade-offs of various forms of management. They also failed to address any nongame species, or to consider the cumulative effects of management activities on wide-ranging species.

The next step was the development of habitat relationships books. These are typified by the book produced for the Blue Mountains in Oregon and Washington (Thomas 1979), the book produced for Colorado (Hoover and Wills 1984), and the book produced for the western Cascades and Coast Range in Oregon and Washington (Brown 1985). These books contained information on all classes of vertebrate wildlife. They also provided rating systems that allowed users to determine the contribution of all habitats to the welfare of a species. For example, Hoover and Wills rated the feeding and cover values of nine structural stages of vegetation in nine forest types. This type of information allowed users to conduct an early form of cumulative effects analysis that could consider a wide variety of wildlife species and the effects of all activities over a broad area (Hoover and Wills 1984). While this was a potentially significant advance, few analyses were completed in operational situations because automated systems were not available to perform the needed calculations and record keeping. Still, these books represented a very significant step forward because they gave biologists and silviculturists information on a wide variety of species and presented a vision of the type of analysis that could be done to explore the interactions between wildlife and timber management.

The next logical step in the integration of timber and wildlife management was the development of automated systems that would provide information on the effects of management on timber and wildlife. One of the earliest ground-breaking attempts at such a system was the DYNAST family of models developed by Boyce (1980). These models allowed users to track changes on large areas of forest land and predict resulting effects on wildlife species. Vegetation change in the models resulted both from management and from natural succession, and users could specify the rates of timber harvest and the rates of succession in different forest types. The user also created the functions relating wildlife species to forest types and successional stages. Subsequent models were patterned after DYNAST, but incorporated information from published habitat relationships books. Such models have been developed for three regions in the Forest Service and for a number of individual forests in several other regions. The model presented in this paper represents one adaptation of these systems. These models have given biologists and foresters a practical way to look at the interactions of wildlife and timber management for a wide variety of species. The analysis can be done over space and time, and so represents the cumulative effects of proposed management activities and natural succession. While these models represent great strides over earlier attempts to integrate timber and wildlife management information, they still are not fully evolved systems. Their ability to analyze spatial relationships is very crude, and the validity of the timber/wildlife relationships has generally not been tested.

3 MANAGEMENT CONTEXT AND ALTERNATIVES

Tools for integration of wildlife and timber information are normally used in a formal planning context. The basic steps involved in planning can be summarized as follows:

- Determine issues, concerns, and opportunities
 - All relevant social and resource issues are identified and examined. If planning is being done under the blanket of some higher-order plan, the objectives from that plan are included in this examination. The final product of this step is the description of a desired future condition for the area, including objectives for all resources of interest.
- Identify current situation and potential futures
 - Appropriate inventory information is gathered and used to describe the current situation for all resources of interest. Projections are made of the potential situations for all those resources. The final product is a description of the existing situation and the capability of the area to meet the desired future condition.
- Develop alternative management actions
 - Alternatives are constructed that include a variety of possible resource management activities and various schedules for their implementation. The output of this step is a description of the alternatives, including what is to be done, and when and where it is to be done.
- Analyze alternatives
 - The effects of each of the alternatives on each of the resources is determined. This is the primary application of the tools being discussed in this paper. The product is a summary of resource outputs and effects under each alternative and a determination of how well the alternatives meet the desired future condition for the area.
- Choose and implement an alternative and monitor its effects
 - A management decision is reached based on the information from the above step. That decision is implemented and its effects are monitored. One of the significant questions in the monitoring effort is whether we accurately projected the effects of our management decision.

It is important that this process be directed at an area that is large enough and appropriately delineated to be biologically meaningful. It is also important that the analysis of management effects be carried out over time so that it looks at the cumulative effects of management in the area. To be useful in this process, a tool must be able to do the following:

- Represent a large enough area to be meaningful.
- Represent a reasonable future time.
- Represent a reasonable range of management activities.
- Determine effects on timber and wildlife, including spatial interactions, with a useful degree of reliability.
- Be readily available and accessible to the average user.

The tools available for this job represent various compromises. None completely fulfills all five criteria, but they all represent improvements over previous attempts at integration of wildlife/timber information.

One class of tool is able to represent timber/wildlife interactions for single forest stands (Brand *et al.* 1986; Moeur 1986). These tools were adapted from existing stand simulation models, and they incorporate functions for productivity of specific wildlife species. Because they are built on stand simulation models, they can represent stand management practices in great detail. Their projection of vegetation structure is also quite detailed, but often limited by a traditional forester's view of vegetation. Their major drawback is the limitation of looking at one stand of vegetation at a time. This geographic scope limits their utility for

cumulative effects analysis and meaningful analysis for any wide-ranging species. Attempts have been made to run such models for many stands of vegetation simultaneously (Moeur 1986), but the resulting systems are cumbersome.

At the other end of the geographic scale are a variety of area level models similar to the one described in this paper. These models can all trace their heritage to the DYNAST models produced by Boyce (1980). Their major advantages are accessibility to potential users and the ability to represent large forest areas. The first of these was developed for the Rocky Mountain Region of the Forest Service. This model forces the user to describe the forest in terms of summarized acres by forest type and successional stage. It is completely lacking in spatial resolution. It also provides the user little flexibility in describing management actions. Clearcutting is the only silvicultural practice that can be modeled. On the positive side, the model is simple to run and uses readily available inventory data.

This initial model was extensively modified for application on the Mark Twain National Forest in Missouri. Intermediate management practices (thinning, burning, etc.) were added, more flexibility was built in so that harvest activities could be directed at specific age classes of vegetation, and the ability to consider type conversions from one vegetation type to another was incorporated. In its application to the Mark Twain National Forest, the vegetation management model was linked to PATREC models of wildlife species that had been developed specifically for the Mark Twain National Forest (Kirkman *et al.* 1986). Some of these have been formally validated. They may be more realistic than the models used in the Rocky Mountain Region. However, their consideration of spatial interactions is still relatively crude.

The model presented in this paper represents another extensive modification of the Rocky Mountains model. It is distinguished by: (1) a structure built around individual forest stands and management specifications for those stands, (2) automated linkages to inventory systems, and (3) the ability to represent a variety of stand management and habitat improvement practices. Because of its stand-oriented structure, it lends itself to more detailed consideration of spatial interactions. At the current time, however, there is no explicit modeling of those interactions.

All of the above models operate as simulations, and they are deterministic in nature. Efforts have also been made to link wildlife models to area level optimization models for vegetation (Holthausen 1986). Such models have not been broadly applied, largely because of their complexity and lack of user accessibility.

A promising development is the recently described TEAMS modeling system. This system is built around a geographic information system (GIS). It is designed to allow the incorporation of a variety of software for representation of management activities, forest succession, and habitat relationships of species. Its major advantage is the ability to incorporate and represent specific spatial relationships. It has not yet been widely applied, and may prove to be cumbersome in practical application. However, it clearly represents an important advance and the first step towards spatially realistic tools for integrating timber and wildlife management information.

4 CASE EXAMPLE OF A TIMBER-HABITAT MANAGEMENT TOOL

4.1 Introduction

The Chattahoochee-Oconee National Forest (C-O) is an area of approximately 850 000 acres (350 000 ha) located in northern Georgia, USA. The forest lies in the southern Appalachian Mountains and the upper Piedmont area of Georgia. The mountains (Chattahoochee National Forest) have a continental climate with warm summers and cool winters. The Piedmont (Oconee National Forest) has a subtropical climate with hot summers and mild winters. Annual precipitation ranges from 48 inches in the Piedmont to 75 inches in the mountains. Forest cover is predominantly southern pine (*Pinus* spp.) in the Piedmont and a mixture of pine and hardwoods in the mountains. Primary game animals are whitetailed deer (*Odocoileus virginianus*), eastern wild turkey (*Meleagris gallopavo*), eastern gray squirrel (*Sciurus carolinensis*), ruffed grouse

(*Bonasa umbellus*), and black bear (*Ursus americanus*). The management goals of the forest seek to provide a sustained yield of forest products and services through multiple-use management while protecting and enhancing the natural resources.

The Land and Resource Management Plan (LRMP) for the Chattahoochee-Oconee National Forest was approved for implementation in 1985. As resource managers work together to implement the LRMP, interdisciplinary teams of foresters, wildlife and fisheries biologists, soil scientists, hydrologists, and other specialists are formed to develop and evaluate management alternatives. These interdisciplinary teams develop various combinations of timber harvests, prescribed burns, wildlife and fish habitat improvements, and transportation systems that will address the goals and objectives of the LRMP. These combinations of activities, or alternatives, are evaluated by the team and a preferred alternative is recommended to the line officer, the District Ranger.

The Forest Service has developed an analysis system to support implementation of the LRMP. The system, called IMLEM, provides a linkage between the LRMP and project design. The link is provided by a series of computer programs that are used at the Ranger District and Forest Supervisor's offices. The programs rely on stand-level information that has been collected through field examination by certified field examiners and silviculturists. Data from the field are stored in a district level database called CISC. The stand-level information is stored in a multi-stand compartment file. Compartments are 1000- to 1500-acre (400- to 600-ha) subdivisions of the forest.

CISC, an acronym for Continuous Inventory of Stand Conditions, is a region-wide (USDA Forest Service Southern Region) system that resides on the local Ranger District computers. The database includes information on forest type, age, size, condition class, land class, site index, management area, and cultural treatments proposed for each stand in a compartment. IMLEM uses this data, along with data entered interactively by the user, to generate information useful in project alternative development and analysis. The IMLEM software, introduced in 1986, is currently used on all eight Ranger Districts on the Chattahoochee-Oconee. It not only provides analysis information, but generates reports that become appendices to the Project Environmental Assessments.

The IMLEM system is composed of nine subprograms that appear to the user in the format in Exhibit A. A brief description of each option in the IMLEM menu will be given here.

Exhibit A

SELECT ONE OF THE FOLLOWING:

- 1 - Retrieve stand data with GETCISC
- 2 - ENTER36 - Enter stand data from '36'
- 3 - EDIT36 - Edit stand data
- 4 - Run CAND
- 5 - Run CompPATS
- 6 - Run SELECT
- 7 - Run TEAMS
- 8 - Run CHHABCAP
- 9 - Obtain Additional Hardcopies
- 10 - Exit to the Command Line

1) GETCISC

This subroutine allows the user to retrieve a copy of the compartment data file from the CISC database. This copy is then available for editing or use in the subsequent subroutines.

2) ENTER36

If no stand data have been entered into the system previously, this subroutine allows the user to build a CISC file from scratch. (The "36" designation comes from the Forest Service Southern Region form number 2400-36 which is a paper copy input form for the CISC file.)

3) EDIT36

If data have been entered into the system either by GETCISC or ENTER36, they can be edited by the user with this subroutine.

4) Run CAND

CAND provides the link between the Forest LRMP and compartment-level analysis. This subroutine uses the CISC data file to generate a list of all stands within a compartment that are "candidates" for timber treatments. This is done through the use of Analysis Area Identifiers (AA's). An Analysis Area Identifier is a number that associates a stand in the current database with an analysis area that was described in the FORPLAN model used during the LRMP process. Each analysis area in FORPLAN was described by a unique set of the following attributes:

- Productivity Class
- Forest Type
- Drainage Basin Response Unit (DBRU)
- Management Type
- Productivity Class
- Condition Class
- Stand Age
- Recreation Opportunity Spectrum (ROS)

The CAND subroutine first associates each stand within a compartment with an AA number. It then follows a series of pre-determined selection criteria to identify and prioritize these stands for intermediate and regeneration treatments. The result is a Candidate Stand Listing (Appendix A) which identifies each stand recommended for thinning, clearcutting, shelterwood, seedtree, or group selection treatment based on silvicultural criteria. The output also identifies the regeneration period for all other stands. This appears as a 1-digit number in the column titled "RG PD" and indicates the regeneration period in 10-year increments.

5) Run CompPATS

The CompPATS (Computerized Project Analysis of Timber Sales) subroutine provides automated cumulative effects analysis for projects involving up to five compartments (5000–10 000 acres) and five project alternatives. Stand-level inventory data are provided by the CISC compartment data files. The user is prompted to input stand and compartment-level treatment data and economic and resource response coefficients. The program then generates tables that display outputs and effects for alternative timber sale projects for the area under analysis (Appendix B). The output focuses on LRMP issues including conversion, herbicides, roads, wildlife, soil, and water. The report generated by this subroutine becomes an appendix to the Project Environmental Assessment (EA).

6) Run SELECT

After the project analysis is completed and the preferred alternative is chosen, the user executes the SELECT program. This interactive program prompts the user to identify the preferred alternative and the LRMP alternative. SELECT then generates a stand and compartment file for each project that includes stand-level inventory data, treatment data, resource outputs, costs, and economic benefits. This file serves as input to the TEAMS program described below.

7) Run TEAMS

At the end of each fiscal year, the forest interdisciplinary team compiles a report that compares projected and actual costs, effects, outputs, and services for that year's projects. TEAMS is a software package that tracks major costs, outputs, and effects *expected* from the silvicultural prescriptions developed during the year. This program is run only at the Forest Supervisor's office and, in essence, accumulates the selected alternatives for each proposed project. The report sums the projected outputs from the SELECT subroutine and produces forest totals. This report is used in monitoring for plan compliance.

8) Run CHHABCAP

CHHABCAP (CHattahoochee HABitat CAPability) is a computer program that uses CISC data and user input to calculate habitat capability units (HCU), wildlife and fish user days (WFUD), and a summary of acres of forest working group by age class (Appendix C). In its present form, HCUs are calculated for white-tailed deer (*Odocoileus virginianus*), eastern wild turkey (*Meleagris gallopavo*), eastern gray squirrel (*Sciurus carolinensis*), ruffed grouse (*Bonasa umbellus*), and cavity-nesting species. Estimates of mast and browse production are calculated in pounds per acre and den trees are estimated in number per acre. Wildlife and Fish User Days are totaled for the analysis area and a dollar value is then calculated.

The outputs from the CHHABCAP program are the same as the wildlife outputs from the CompPATS program. The reason for including CHHABCAP as a separate option in the menu is that CHHABCAP offers the user the option of simulating stand growth and projecting effects over time. The user may specify any number of future reporting years.

9) Obtain Additional Hardcopies

Self explanatory.

10) Exit to the Command Line

Self explanatory.

4.2 The CHHABCAP Model

CHHABCAP4 is a simple coefficient model that describes the number of acres and age of a given forest type required to support one animal throughout the year. The basic concept includes considerations of maximum recorded home range sizes, year-round habitat requirements of each species modeled, and good knowledge of the biological and structural characteristics of each forest type and age. Also incorporated into the model are the effects of major silvicultural treatments such as thinning and prescribed burning. The model also considers the effects of sod openings created in the forest for edge, food, and diversity.

4.2.1 Species/habitat relations modeled in CHHABCAP4

Deer

White-tailed deer in the southern Appalachians are primarily browsing animals with recorded home ranges of less than 1 square mile. During the period of availability, they feed heavily on acorns, forgoing all other foods when this food is available. Years of mast acorn failure are followed by years of poor reproductive success. Acorn crop failure years increase the consumption of forages available in sod openings, roadsides, and similar environments. Rosebay rhododendron is eaten heavily during these years of mast failure, even though it is not very nutritious.

Heavy use of flush annual growth is made in early spring, with soft fruits being added by early summer. In the southeastern United States, deer do not "yard," although in the mountains they usually shift their home ranges in order to use evergreen food sources in coves, or acorns on upland hardwood ridges.

Grouse

In the southern Appalachians, grouse seasonally occupy a variety of habitat types. Mature upland hardwoods with adequate drumming sites are very important, but regeneration areas 10–15 years or so after cutting are used heavily in the fall. In the model, grouse range is assumed to lie above 2000 feet.

Wild turkey

Adequate brood range is the most frequently encountered limiting factor for turkeys in the mountains. Nests are frequent in regeneration areas from 3–5 years in age. Broods use grassy openings and log roads for bugging if the slopes are gentle. Turkeys use many foods, and diversity created by age classes improves habitat greatly. Disturbance in the forest environment does not seem to be very limiting to turkeys, although range shifts are sometimes seen with high levels of noise such as are found in outdoor recreation vehicle areas.

Cavity nesters

Dens and snags increase in the forest with advancing age. The model contains a den and snag predictive model based on average conditions measured in the forest. It is assumed in the model for cavity nesters that habitat capability for these species that require dens and snags can be predicted from the quality of the habitat for dens and snags.

Gray squirrel

Gray squirrels reach their greatest densities in mature upland hardwoods, but anywhere there is denning opportunity and hard mast they will be found. Few pine stands are totally devoid of these attributes, although the Virginia pine type carries but few squirrels.

Sediment yield

COMPATS includes a sediment yield model that predicts the amount of sediment entering streams due to management activities. The output data provide existing baseloads, predicted increases, and a value known as "threshold." The latter value represents what is believed to be an "LD 50" level for fish habitat quality.

4.3 CHHABCAP4 Source Listing

See Appendix D for a complete listing of the Fortran source code for CHHABCAP.

5 TECHNOLOGY TRANSFER

The IMPLEM system is installed and operational on the eight Ranger Districts of the Chattahoochee-Oconee National Forest. A user's guide has been available for 3 years. Each district has at least one and as many as five employees who are proficient in the use of the system. The entire system has also been adapted by the Ouachita National Forest in Arkansas and Oklahoma. Other forests are adapting CHHABCAP to fit their individual needs.

The USDA Forest Service Southern Region (R8) has been transferring this technology to the forests within the region as each forest requests it. The Southern Region has two Wildlife and Fish Habitat Relationships personnel who handle the technology transfer. The computer programs are taken to the requesting forest on computer tape, installed on the forest mini-computer, and then adapted to the individual forest's situation.

The Eastern Region of the USDA Forest Service has been adapting the CHHABCAP model for use on eastern forests. Currently, the Monongahela National Forest in West Virginia and the Nicolet National

Forest in Wisconsin have operational versions of the habitat capability model. These two forests are refining the response coefficients to reflect local habitats. Technology transfer in the Eastern Region is being done by the Regional Wildlife and Fisheries Habitat Relationships Coordinator. The models are available as "dump files" that can be retrieved electronically by other forests from the regional office.

The Land Management Planning Group in the Southern Region is also working to convert the IMPEM system to operate in a relational database environment. The system is being restructured in the ORACLE software package with a modular framework. The objective of this project is to make the system more portable and adaptable, thereby facilitating its adoption and use.

The IMPEM system has also been demonstrated at the Wildlife Habitat Continuing Education modules at Virginia Polytechnic Institute and State University in Blacksburg, Virginia, and at Utah State University in Logan, Utah.

6 EVALUATION

The Chattahoochee-Oconee National Forest has recently added a Wildlife and Fisheries Habitat Relationships position to the Wildlife Staff. The primary duties of this position include the validation and testing of the habitat models in CHHABCAP and IMPEM. The forest is already monitoring the effects of implementation of the Land and Resource Management Plan. The information derived from monitoring will be useful in the validation of these models.

7 QUESTIONS TO BE ANSWERED

Some of the questions still to be answered about this system are:

1. What will be involved in converting these models to operate in the Geographic Information System environment?
2. How adequate are the coefficients in the models?
3. What are the limits to the benefits of prescribed burning, clearcutting, wildlife openings, etc.?

8 SUMMARY

The IMPEM system is a set of first-generation computer models that provide valuable information to resource managers. It facilitates the process of analyzing alternatives and promotes informed decisions. Work is under way to improve both the models and the computer system in which the models now operate.

**APPENDIX A. Sample output from the Candidate Stand program (CAND).
Candidate Stands for BRASSTOWN District, Compartment 317 (Date of Report- 6/17/87)**

AA NO	RG PD	STD NO	LAND CLASS	FOR TYPE	ST CC	ACRES	MOC	AGE** YRS	WL	CISC MGTP	LMP MGTP	SI MT	PC FT	REG METH	TOTCCF THIN	SAWMBF /ACRE	MA /ACRE	NO	MANAGEMENT AREA NAME
18	3	1	540	56	12	30	5	71	40	56	—	91	3	—	YES	000	000	16	GENERAL FOREST
18	3	2	540	56	12	22	1	71	40	56	—	91	3	—	—	—	—	16	GENERAL FOREST
18	3	3	500	56	10	33	2	93	40	56	—	91	3	—	—	—	—	16	GENERAL FOREST
62	5	4	500	53	6	34	2	71	40	3	—	81	3	—	—	—	—	16	GENERAL FOREST
66	2	5	500	3	13	15	1	21	40	3	—	81	1	—	—	—	—	16	GENERAL FOREST
18	3	6	540	56	12	88	1	71	40	56	—	91	3	—	—	—	—	16	GENERAL FOREST
18	3	7	540	50	12	46	1	71	40	56	—	91	3	—	—	—	—	16	GENERAL FOREST
33	3	8	700	53	6	64	2	71	40	53	—	62	4	—	—	—	—	16	GENERAL FOREST
62	5	9	770	53	7	36	2	71	40	3	—	62	4	—	—	—	—	16	GENERAL FOREST
15	10	10	500	56	13	50	1	12	40	56	—	91	3	—	—	—	—	16	GENERAL FOREST
11	3	11	500	56	10	18	2	98	40	56	—	101	2	—	—	—	—	16	GENERAL FOREST
18	3	12	540	56	12	43	1	71	40	56	—	91	3	—	—	—	—	16	GENERAL FOREST
15	10	13	500	56	13	34	1	13	40	56	—	91	3	—	—	—	—	16	GENERAL FOREST
120	4	14	770	53	8	45	2	71	40	53	—	72	3	—	—	—	—	16	GENERAL FOREST
109	1	15	540	56	12	96	1	61	40	56	HDWD	91	3	SHEL***	2 804	487	—	15	SEMI-PRIM NON-MOT
18	0	16	880	56	12	50	1	61	40	56	—	91	3	—	—	—	—	15	SEMI-PRIM NON-MOT
109	1	17	540	56	12	76	1	71	40	56	HDWD	91	3	SHEL***	2 804	487	—	5	APPALACHIAN TRAIL
120	4	18	700	53	7	25	2	71	40	53	—	62	4	—	—	—	—	15	SEMI-PRIM NON-MOT
33	3	19	700	53	7	24	2	71	40	53	—	62	4	—	—	—	—	15	SEMI-PRIM NON-MOT
33	3	20	500	53	6	20	2	71	40	53	—	71	3	—	—	—	—	16	GENERAL FOREST
18	3	21	500	56	10	16	2	93	40	56	—	91	3	—	—	—	—	16	GENERAL FOREST

Age Summary

AGE	# STNDS	ACRES
11-20	2	84
21-30	1	15
61-70	2	146
71-80	13	553
91-100	3	67
TOTAL		865

Candidate Summary

HARVEST	# STNDS	ACRES
CLEARCUT	0	0
SHELTERWOOD	2	172
SEEDTREE	0	0
THINNED	1	30
TOTAL		865

Average Compartment Age= 65 Years
 % Total Area 20 Years Old or Less= 10%
 % Area in Regen Candidates= 20%
 *** Special Management Area- Modify the regeneration method according to the Forest Plan

APPENDIX B. Sample output from the CompPATS program.

Listing of Treated Stands in Each Alternative for Brasstown District, Compartment 317
(Fiscal Year of Sale Implementation - 1990)

ALT A ST #	Alternative Forest Type	Condition Class	Age	Trt Ac	Method of Cut	Cultural Treatment
11	YL POP-WH O-NR O	MATURE SAWTMBR	99	18	CLEARCUT	NATL REGENERATION WITH HAND TOOLS
ALT B ST #	Alternative Forest Type	Condition Class	Age	Trt Ac	Method of Cut	Cultural Treatment
3	YL POP-WH O-NR O	MATURE SAWTMBR	94	33	CLEARCUT	NATL REGENERATION WITH HAND TOOLS
11	YL POP-WH O-NR O	MATURE SAWTMBR	99	18	CLEARCUT	NATL REGENERATION WITH HAND TOOLS
20	WH OK-RD OK-HK	SPARSE SAWTMBR	72	20	CLEARCUT	NATL REGENERATION WITH HAND TOOLS
ALT C ST #	Alternative Forest Type	Condition Class	Age	Trt Ac	Method of Cut	Cultural Treatment
3	YL POP-WH O-NR O	MATURE SAWTMBR	94	33	CLEARCUT	NATL REGENERATION WITH HAND TOOLS
11	YL POP-WH O-NR O	MATURE SAWTMBR	99	18	CLEARCUT	NATL REGENERATION WITH HAND TOOLS

* Candidate for treatment in the first decade.

Outputs and Effects for Sale Implemented in 1990 on Brasstown District, Compartment 317
Date of report - 8/26/87

	NO-ACTION	ALT A	ALT B	ALT C
TREATMENT (acres)				
Clearcut	0	18	71	51
Cand Ac regen	0	0	0	0
Non-cand regen	0	18	71	51
% Non-cand regen	0	100.	100.	100.
Avg Opening Size	42.	34.	31.	34.
Pct in Openings	10.	12.	18.	16.
Site prep	0	18	71	51
ROADS & NEW ROAD CONST (miles)				
Existing open roads	1.5	1.5	1.5	1.5
Existing closed roads	.0	.0	.0	.0
Closed construction	.0	.0	.9	.9
Temporary construction	.0	.6	.9	.6
ROAD DENSITY (miles per sq mile)				
System roads	1.11	1.11	1.78	1.78
Temporary roads	.00	.44	.67	.44
TOTAL	1.11	1.55	2.44	2.22
TYPE CONVERSIONS (acres)				
Net change h2wds	0	0	0	0

APPENDIX B. (Cont'd.)

Outputs and Effects for Sale Implemented in 1990 on Brasstown District, Compartment 317
Date of report - 8/26/87

	NO-ACTION	ALT A	ALT B	ALT C
WILDLIFE				
Deer (an/sqmi) *	12.22	14.11	19.51	17.58
Turkey (an/sqmi)	22.23	21.90	20.79	21.29
Squirrel(an/sqmi)	206.75	202.43	187.86	194.52
Grouse (an/sqmi)	13.55	15.08	19.59	17.89
Cav nstr(an/sqmi)	88.18	86.46	81.41	83.31
Mast (pds/ac)	106.04	104.44	96.27	101.50
Browse (pds/ac)	14.37	18.26	27.82	25.39
Dens (dens/sqmi)	4251.75	4151.86	3857.76	3968.74
SEDIMENT (tons)				
Existing Roads	19.2	19.2	19.2	19.2
Road-related	.0	3.4	5.1	3.4
Harvest-related	.0	2.2	8.7	6.2
Total	19.2	24.8	33.0	28.8
Threshold	67.6	67.6	67.6	67.6

* Featured species.

** Below 1200 ft. MSL grouse populations are limited by elevation.

*** Total sediment exceeds the threshold.

APPENDIX B. (Cont'd.)

Outputs and Effects for Sale Implemented in 1990 on Brasstown District, Compartment 317
Date of report - 8/26/87

	NO-ACTION				ALT A				ALT B				ALT C			
	Total Project	Un \$ LMP	or YI	Proj	Total Project	Un \$ LMP	or YI	Proj	Total Project	Un \$ LMP	or YI	Proj	Total Project	Un \$ LMP	or YI	Proj
TIMBR YLDS- REGN (vol)																
Hdwd STMBF	0.	.0	.0	.0	126.	6.4	7.0	414.	5.6	5.8	324.	6.4	324.	6.4	6.4	6.4
Hdwd RWCCF	0.	.0	.0	.0	72.	19.6	4.0	54.	17.5	3.0	72.	19.6	72.	19.6	4.0	4.0
TIMBR YLDS- THIN (vol)																
TIMBER STUMPAGE (\$)																
Hdwd STMBF	0.	.0	.0	.0	10090.	100.1	80.0	28800.	96.8	69.6	22950.	100.1	22950.	100.1	70.8	70.8
Hdwd RWCCF	0.	.0	.0	.0	43.	.2	.6	32.	.2	.6	43.	.2	43.	.2	.6	.6
Total	0.				10123.			28832.			22993.		22993.			
CULTURAL TRT COSTS (\$)																
Total	0.				0.			0.			0.		0.			
ROAD COSTS (\$)																
Closed Construction	0.	.0	.0	.0	0.	.0	.0	22500.	26.8	25.0	22500.	26.8	22500.	26.8	25.0	25.0
Total	0.				0.			22500.			22500.		22500.			
% Road used- First pd	0.				100.			83.			77.		77.			
% Road used- Second pd	0.				0.			17.			23.		23.			
TIMBER COSTS (\$)																
Sales Prep & Harv Ad	0.				1764.	83.	83.	5796.			4536.	83.	4536.			
SP for Clearcut	0.	0.	0.	0.	1494.			5693.	83.	83.	4233.	83.	4233.	83.	83.	83.
Total Tbr	0.				3258.			11689.			8769.		8769.			
Total - 1= Pd Rd+ Tbr	0.				3258.			30265.			26155.		26155.			
S/C (Sales Prep + HA)	1.00				5.74			4.97			5.07		5.07			
S/C (SP + HA + Est)	1.00				3.11			2.47			2.62		2.62			
S/C (SP+HA+Est+Rd-1)	1.00				3.11			.95			.88		.88			

APPENDIX C. Sample output from the CHHABCAP program

Habitat capability for 865 acres in the C317 analysis

Reporting year - 1989

Featured species - N/A

Species	Habitat capability		WFUDS
	Animals	#/sq. mi.	
Deer	17	13.	148
Turkey	30	23.	741
Squirrel	279	207.	20
Grouse	18	14.	8
Cavity nester	119	89.	0
Mast	91727	67868.	0
Browse	12427	9195.	0
Dens	5747	4252.	0

Total \$ of WFUDS = 16545

Summary of acres for this analysis unit

White pine	21-30	15.
Cove hardwood	11-20	84.
Cove hardwood	61-70	146.
Cove hardwood	71-80	305.
Cove hardwood	91-100	67.
Upland hardwood	71-80	248.

APPENDIX D. Fortran source code for the CHHABCAP habitat capability program

```
C      PROGRAM CHHABCAP4.F77
C
C      The Chattahoochee Habitat Capability program.
C
C      A program which calculates habitat capability, WFUD's,
C      hard mast capability, den capability, and winter browse.
C      Input data is read from the 2400-36, and the output can
C      be written to the terminal, line printer, and/or listfile.
C
C      *** Modified July, 1987 to allow use of data files retrieved
C      *** from the CISC data base by the program GETCISC as input
C
C      *** Modified June 1988 to correct incorrect computations
C      *** involving Species coefficients and treatments.  DMB.
C
C      VARIABLES:
C
C      TMENT(I) - an array of labels for treatment type
C      CLASS(I) - an array of labels for age classes
C      FTYPE(I) - an array of labels for the forest type
C      ANAREA - the area name (assigned by user)
C      DCOEFS2 - number of deer per acre by working group and
C              ageclass - untreated
C      DCOFT - number of additional deer per acre by working
C              group for thinning
C      DCOFB - number of additional deer per acre by working
C              group for burning
C      TCOEFS2 - number of turkey per acre by working group
C              and age class - untreated
C      TCOFT - number of additional turkey per acre by working
C              group for thinning
C      TCOFB - number of additional turkey per acre by working
C              group for burning
C      SCOEFS2 - number of squirrel per acre by working group
C              and age class - untreated
C      SCOFT - number of additional squirrel per acre by working
C              group for thinning
C      SCOFB - number of additional squirrel per acre by working
C              group for burning
C      GCOEFS - number of grouse per acre by working group and
C              age class - untreated
C      GCOFT - number of additional grouse per acre by working
C              group for thinning
C      GCOFB - number of additional grouse per acre by working
C              group for burning
C      CCOEFS - number of cavity nesters per acre by working
C              group and age class - untreated
C      MCOEFS - pounds of hard mast per acre by working group
C              and age class - untreated
```


APPENDIX D. (Cont'd.)

C DNCOEF5 - number of dens per acre by working group and
 C age class - untreated
 C BCOEF5 - pounds of browse per acre by working group and
 C age class - untreated
 C BCOEFST - pounds of browse per acre by working group and
 C age class - thinned
 C BCOEF5B - pounds of browse per acre by working group and
 C age class - burned
 C PFILE - a variable holding the name of a data file to
 C be opened
 C FT(ST) - forest type of a stand
 C AC(ST) - number of acres in the stand
 C BD(ST) - birthdate of the stand
 C MT(ST) - management type of the stand
 C REGYR(ST) - regeneration year of the stand
 C BRNYR(ST) - year stand is to be burned
 C THNYR(ST) - year stand is to be thinned
 C TAC - total acres
 C COEF5(A,B,C,D) - an array into which the individual coefficient
 C data files are read
 C CAP(S) - the capability units for each species S
 C UDAY(I) - an array of coefficients dealing with user days
 C RPAVAL(I) - an array of RPA values
 C WFDAY(I) - wildlife and fisheries day (used in calculating WFUD's)
 C WFUDVA(I) - WFUD value for species I (Wildlife and Fisheries
 C User Day)
 C ACARY(AGE,WG,TRT) - number of total cares in the specified
 C age class, working group, and treatment category
 C DENS(I) - the number of animals or pounds per square mile
 C for species I
 C ACOP(ST) - the number of acres in openings for stand #ST
 C ACT(I) - a running sum of the acres that have been thinned
 C or burned

PROGRAM HABCAP

IMPLICIT INTEGER (A-Z)

COMMON BUG

LOGICAL BUG

CHARACTER*1 ANS, YES/'Y'/, NO/'N'/, LF, REPANS

CHARACTER*14

```

* FTYPE(7)/ 'YELLOW PINE ', ' WHITE PINE ', 'VIRGINIA PINE ',
*           'PINE-HARDWOOD ', 'BOTLAND HARDWD', 'COVE HARDWOOD ',
*           'UPLAND HARDWD '/,
* SPECIE(8)/ 'DEER          ', 'TURKEY          ', 'SQUIRREL          ',
*           'GROUSE         ', 'CAVITY NESTER ', 'MAST             ',
*           'BROWSE         ', 'DENS          ', '/',
* FTSPEC
  
```

CHARACTER*24 ANAREA, LIMIT*18

CHARACTER*24 PFILE

CHARACTER*7

```

* CFILE(10)/ 'DCOEF52', 'TCOEF52', 'SCOEF52', 'GCOEF5', 'CCOEF5',
*           'MCOEF5', 'BCOEF5', 'DNCOEF5', 'BCOEFST', 'BCOEF5B' /,
* TMENT(4)/ ' ', 'THINNED', 'BURNED', 'TH & BN' /,
  
```

APPENDIX D. (Cont'd.)

```
* CLASS(16)/ ' 0-5',' 6-10',' 11-20',' 21-30',' 31-40',
* ' 41-50',' 51-60',' 61-70',' 71-80',' 81-90',
* ' 91-100','101-110','111-120','121-130','131-140',
* ' 141+'/
```

```
LOGICAL INAC, TSPEC(7), REPSW/.FALSE./
```

```
REAL COEFS(16,7,8,3), CAP(8), OPNRAT, C,
* UDAY(8) / 8.96, 24.66, .07, .42, 4*0./,
* RPAVAL(8) / 2*17.85, 2*24.80, 4*0./,
* WFDAY(9), WFUDVA(9),
* ACARY(17,7,4) / 476*0./,
* TAC, DENS(8)
```

```
DIMENSION FT(999),AC(999),BD(999),MT(999),REGYR(999),BRNYR(999),
* THNYR(999),ACT(4)/4*0/,ACOP(999)
```

```
REAL DCOFT(7)/.013,.013,.009,.012,.013,.013,.012/, ! Deer      thin
* DCOFB(7)/.022,.022,.016,.020,.022,.022,.020/, !      burn
* TCOFT(7)/.002,.002,.002,.002,.002,.002,.002/, ! Turkey   thin
* TCOFB(7)/.020,.020,.020,.020,.020,.020,.020/, !      burn
* SCOFT(7)/.037,.037,.000,.037,.037,.037,.037/, ! Squirrel thin
* SCOFB(7)/.000,.000,.000,.000,.000,.000,.000/, !      burn
* GCFT(7)/.000,.150,.000,.150,.000,.150,.150/, ! Grouse   thin
* GCOFB(7)/.000,.137,.000,.137,.000,.137,.137/ !      burn
```

C Define error messages

```
CHARACTER*25 ERR_1_2 / '<BEL> ERROR -- ENTER 1 OR 2 - '/
CHARACTER*25 ERR_N_Y / '<BEL> ERROR -- ENTER Y OR N - '/
```

```
kbd      = 5      ! screen input
scr      = 6      ! screen output
MAXAGE = 16      ! MAXIMUM AGE CLASS FOR COEFFICIENTS FROM DATA FILES.
IST      = 1      ! Stand number.
lst      = 12     ! listfile specified in CHHABCAP.CLI
coef     = 1      ! file for coef's
TAC      = 0      ! Total acres.
FLAG     = 0
BUG      = .FALSE. ! TRUE shows debugging information.
```

```
CALL TITLE      ! Print title page to screen.
```

```
Write(*,1003)
```

```
1003 Format(/' Show detailed Debug information? (Y/N) ')
```

```
Read(*,'(A1)') ANS
```

```
IF (ANS.EQ.'Y' .OR. ANS.EQ.'y') BUG=.TRUE.
```

```
DO 2 I = 1, 9
```

```
    WFDAY(I) = 0.
```

```
    WFUDVA(I) = 0.
```

```
2 CONTINUE
```

APPENDIX D. (Cont'd.)

 * This section reads the 16 coefficients for a forest type and species.*
 * The coefficients are in a set of files in the same directory as the *
 * program. The last two files 'bcoefst' and 'bcoefsb' contain age- *
 * dependent thinning and burning coefficients for browse. *

```

      WRITE (*, 776)
776  FORMAT(// '1Reading coefficients for:')

      DO 3, K = 1, 10
        OPEN (UNIT=coef, FILE=CFILE(K))
        IF ( K .LE. 8) THEN
          S=K
          T=1
        ELSE

C      The thinning and burning coeffs for browse are age dependent
C      and are stored in files just like regular species coefficients.

          S= 7          ! Species 7 is BROWSE
          T= K-7        ! Adjust treatment number to 2=thin, 3=burn.
        ENDIF

      WRITE (*, 777) K, CFILE(K), S, SPECIE(S), T, TMENT(T)
777  *  FORMAT(/I3, ' File: ', A, ' for Species (S): ', I2, ' ', A,
        ' Treatment (T): ', I2, ' ', A)

      READ (coef, 110) ((COEFS(I,J,S,T), I=1,16), J=1,7)
110  FORMAT(16F4.0)
      IF (BUG) WRITE ( * , 778) ((COEFS(I,J,S,T), I=1,16), J=1,7)
778  FORMAT(10F7.2)

      CLOSE (coef)

3    CONTINUE
      Call Pause

C    When deer, turkey, squirrel and grouse are on thinned or burned
C    acres their coefficients need to be augmented by these values.

      DO 330 A= 1, MAXAGE ! AGE CLASS
      DO 330 F= 1, 7      ! FOREST TYPE
      DO 330 S= 1, 4      ! 1=DEER, 2=TURKEY, 3=SQUIRREL, 4=GROUSE.
      DO 330 T= 2, 3      ! TREATMENT: 2=THIN, 3=BURN
        IF (S.EQ.1 .AND. T.EQ.2) COEFS(A,F,S,T)= DCOFT(F)
        IF (S.EQ.1 .AND. T.EQ.3) COEFS(A,F,S,T)= DCOFB(F)
        IF (S.EQ.2 .AND. T.EQ.2) COEFS(A,F,S,T)= TCOFT(F)
        IF (S.EQ.2 .AND. T.EQ.3) COEFS(A,F,S,T)= TCOFB(F)
        IF (S.EQ.3 .AND. T.EQ.2) COEFS(A,F,S,T)= SCOFT(F)
        IF (S.EQ.3 .AND. T.EQ.3) COEFS(A,F,S,T)= SCOFB(F)
        IF (S.EQ.4 .AND. T.EQ.2) COEFS(A,F,S,T)= GCOFT(F)
        IF (S.EQ.4 .AND. T.EQ.3) COEFS(A,F,S,T)= GCOFB(F)

```

APPENDIX D. (Cont'd.)

330 CONTINUE

```
*****
*
*                               *
*      Stand Description Input Section      *
*                               *
*****
```

```
PRINT *, '<FF> Enter the area's name (to 24 characters).'
PRINT *, ' This name must be a single word or several'
PRINT *, ' words connected by underscores (''_') - '
READ (kbd, '(A24)') ANAREA
```

```
PRINT *, ' Enter the featured species - '
READ (kbd, '(A14)') FTSPEC
```

```
PRINT *, ' Enter the minimum elevation in feet - '
READ *, ELEV
```

```
5 PRINT *, ' Enter the reporting year (yyyy) - '
READ *, REPYR
```

```
PFILE = ANAREA
IF(REPSW) GO TO 504 ! If this is a repeat run
```

C If the stand data has already been entered, don't reenter it.

```
550 PRINT *, ' Is your stand data in a file (Y/N)? - '
READ (kbd, 101) ANS
```

```
* IF(ANS.NE.'Y' .AND. ANS.NE.'N' .AND.
  * ANS.NE.'y' .AND. ANS.NE.'n') THEN
  * WRITE(6,*) ERR_N_Y
  * GO TO 550
  * ENDIF
```

```
*****
*
*                               *
*      Stand Description Input Section      *
*      File Input                          *
*                               *
*****
```

```
IF (ANS .EQ.'Y' .OR. ANS.EQ.'y') THEN ! Stand is in Data File.
  FLAG = 1
  PRINT *, ' Is the file name : 1) CISCnnn?'
  PRINT *, ' or 2) the area name?'
  PRINT *
  WRITE(6,*) ' ENTER 1 OR 2 -- '
502 READ(kbd, '(I1)') REPLY
```

```
IF(REPLY.NE.1 .AND. REPLY.NE.2) THEN
```

APPENDIX D. (Cont'd.)

```

        WRITE(6,*) ERR_1_2
        GO TO 502
    ENDIF

    IF(REPLY.EQ.1) THEN
        COUNT2 = 0 !initialize counter for total number of stands
        OPEN(10,FILE=PFILE,STATUS='NEW', ERR=820)
501    PRINT *, '<LF> How many compartments? '
        READ(kbd,*) INDEX_NUM
        PREV_COUNT = 0 ! initialize variable to keep track of the
                        ! number of stands in the previously
                        ! entered compartment.

C        Retrieve info from the CISCnnn file for every compartment
C        to be included in this area

        DO 500 I=1, INDEX_NUM
            ID = I
            CALL CISC_ENTER(ID, PREV_COUNT, COUNT2) ! Read from CISC
500        CONTINUE

        CLOSE(10)
        NSTNDS = COUNT2
        WRITE(6,801) PFILE, COUNT2
801    FORMAT('1',////////,
*           ' *****'//
*           '      DATA FILE "', A24, '" CREATED'//
*           '      This area contains ', I4, ' stands'//
*           ' *****'//)
        Call Pause
    ENDIF
    IF(REPLY.EQ.2) THEN
        PRINT *, ' Enter the number of stands in this area - '
        READ *, NSTNDS
    ENDIF

*****
*
*           Stand Description Input Section
*           Keyboard Input
*
*****

    ELSE
        ! Stand is NOT in Data File.
C        This option reads data from the keyboard rather than
C        from a data file, and creates a data file using the
C        area name as the file name.
        FLAG = 0
        PRINT *, ' Enter the number of stands in this area - '
        READ *, NSTNDS
503    OPEN (UNIT=10, FILE=PFILE, STATUS='NEW', ERR=820)
        GO TO 8
    ENDIF

```

APPENDIX D. (Cont'd.)

```
C      For the existing data files, read data and perform calculations
C      Open the existing or newly created data file.
504 OPEN (UNIT=10, FILE=PFILE, STATUS='OLD')
      80 READ (10,800) IST,FT(IST),AC(IST),ACOP(IST),BD(IST),
      *          MT(IST),REGYR(IST),BRNYR(IST),THNYR(IST)
      GO TO 12

      ! To create the data file, have user enter information.
8 PRINT 111, IST
111 FORMAT ( ' Enter for stand ',I3,' the Forest type, Acres,',
      *      ' Management Type, and FY Regen ',/ ,
      *      ' ( ENTER 0 if N/A )<NL>' )
PRINT *, ' Enter the forest type          (xxx) - '
READ *, FT(IST)

PRINT *, ' Enter the total acres          (xxxx) - '
READ *, AC(IST)

PRINT *, ' Enter the acres to be kept in permanent wildlife ',
*      ' openings - '
READ *, ACOP(IST)

PRINT *, ' Enter the birthdate            (xxx) - '
READ *, BD(IST)

PRINT *, ' Enter the management type      (xxx) - '
READ *, MT(IST)

PRINT *, ' Enter the regen year           (xxxx) - '
READ *, REGYR(IST)

PRINT *, ' Enter the year it will be burned (xxxx) - '
READ *, BRNYR(IST)

PRINT *, ' Enter the year it will be thinned (xxxx) - '
READ *, THNYR(IST)

C      Decode the forest type code and management type code.

12      IF ( FT(IST) .GE. 100) FT(IST) = MOD( FT(IST),100)
220      IF ( MT(IST) .GE. 100) MT(IST) = MOD( MT(IST),100)

C      This is old code.
C225      IF (REGYR(IST) .GT. 0 ) THEN
C          'ACCOM' is the accomplishment part of the FY regen code
C          ACCOM = MOD( REGYR(IST),10 )
C      ELSE
C          ACCOM = 0
C      ENDIF

C      Determine if the stand has been cut and assign an age.
```


APPENDIX D. (Cont'd.)

```

225      IF ( REPYR .GE. REGYR(IST) .AND. REGYR(IST) .GT. 0) THEN
          ! YES the stand was cut!
          AGE = REPYR - REGYR(IST)
          TP = MT(IST)                ! USE Management Type.

      ELSE
          ! Stand was not cut.
          IF (BD(IST) .EQ. 0 ) THEN
              AGE = 0
          ELSE
              AGE=REPYR-(BD(IST)+1000) ! USE Birth Date.
          ENDIF
          TP=FT(IST) ! USE Forest Type.
      END IF

C      Determine the treatment type and years since of treatment.

C      When no thinning or burning has been done the Treatment is
c      coded as TRT=1. When a REPORTING year is 0 to 5 years
C      following the Thinning year then treatment is recorded as
C      TRT=2. Example: Thin in 1995 and report in 2001 uses the
C      regular coefficients (TRT=1) byt a Thin year of 1995 with a
C      Reporting year of 1999 will use the basic coefficients
C      augmented by the thinning coefficients TRT=2.
C      Burning works the same way but uses a 0 to 3 year effective
C      time span (TRT=3). If Thin and Burn are both effective
C      within the reporting period, then TRT=4.

      TRT = 1                        ! Use Basic Coefficients.
      TYRS = REPYR - THNYR(IST)
      BYRS = REPYR - BRNYR(IST)
      IF (TYRS.GE.0 .AND. TYRS.LE.5)      TRT = 2      ! THIN
      IF (BYRS.GE.0 .AND. BYRS.LE.3)      TRT = 3      ! BURN
      IF (TYRS.GE.0 .AND. TYRS.LE.5 .AND.
*      BYRS.GE.0 .AND. BYRS.LE.3)      TRT = 4      ! BOTH

888      IF (BUG) WRITE( 6,888) AGE, REPYR, THNYR(IST), BRNYR(IST),TRT
      FORMAT(' AGE, REPYR, THNYR, BRNYR, TRT=', 5I8)
      IF (BUG) Call Pause

C      This is old code that did not work right.
C      IF ( BRNYR(IST).EQ.REPYR .AND. BRNYR(IST).NE.THNYR(IST))
C      *      TRT=3
C      IF ( THNYR(IST).EQ.REPYR .AND. BRNYR(IST).NE.THNYR(IST))
C      *      TRT=2
C      IF ( BRNYR(IST).EQ.REPYR .AND. BRNYR(IST).EQ.THNYR(IST))
C      *      TRT=4
C      IF (BRNYR(IST).NE.REPYR .AND. THNYR(IST).NE.REPYR)
C      *      TRT=1

C      Use Sub GETAC to allocate acres by Age, Working Group and
C      Treatment and return ACARY(AGE,WG,TRT).

```

APPENDIX D. (Cont'd.)

CALL GETAC (ACARY,TP,AC(IST),ACOP(IST),AGE,kbd,WG,TRT,MAXAGE)

C If the forest type or management type is invalid, print an
C error messages and reenter all data for this stand.

```

      IF ( WG .EQ. 0) THEN      ! invalid FT or MT.
        PRINT 112, IST
        FORMAT(' <bel> Invalid forest type or management type. ',
          *      'Re-enter data for stand # ',I3,/)
        GOTO 8
      ELSE                      ! valid FT or MT
        Write the info for this stand to the data file.
        IF(FLAG.EQ.0)
          *      WRITE (10,800) IST,FT(IST),AC(IST),ACOP(IST),BD(IST),
          *      MT(IST),REGYR(IST),BRNYR(IST),THNYR(IST)
        IST=IST+1 ! calculate the number for the next stand
        when not all stands are entered and data is being
        entered on the screen:
          IF ((IST .LE. NSTNDS) .AND. (FLAG. EQ. 0)) GOTO 8
        when not all stand info has been read from the data file:
          IF ((IST .LE. NSTNDS) .AND. (FLAG. EQ. 1)) GOTO 80
        IST = NSTNDS ! RESTORE TO MAXIMUM VALUE.

```

ENDIF

C Calculate the total acres for this unit

```

      DO 16 I = 1, 7
        TAC = TAC + ACARY(17,I,1)
16  CONTINUE

```

```

      PRINT *,
      * '<FF> Do you want your output to go to the listfile? (Y/N)- '
      READ (kbd,101) ANS
      IF (ANS .EQ. YES) THEN
        out = 1st
      ELSE
        out = scr
      END IF

```

C Calculate the capability index for each species

```

      DO 22 S = 1, 8          ! for each species
        CAP(S) = 0.0         ! Initialize summation variable.
        IF (BUG) WRITE( *, 1001) S, SPECIE(S)
1001  Format(/' Computing CAP Index for Species (S)=', I3,' ',A)

        DO 20 F = 1, 7       ! for each type
          DO 20 A = 1, MAXAGE ! for each age class
            DO 20 T=1, 4      ! For each Treatment.
              IF ( ACARY(A,F,T) .EQ. 0. ) GOTO 20 ! SKIP WHEN THERE ARE NO

```

ACRES.

APPENDIX D. (Cont'd.)

```

C= COEFS(A,F,S,1) ! Always use basic coefficient
If (T.EQ.2) C= C + COEFS(A,F,S,2) ! Add in thin coefficient
If (T.EQ.3) C= C + COEFS(A,F,S,3) ! Add in burn coefficient
If (T.EQ.4) C= C + COEFS(A,F,S,2) + COEFS(A,F,S,3) ! Both.

```

```

CAP(S)= CAP(S) + ACARY(A,F,T)* C

```

```

      IF (BUG) WRITE(*, 891) A, F, S, T, ACARY(A,F,T),
      *                      (COEFS(A,F,S,TT), TT=1,3), C
891  FORMAT(/' Age=', I2, ' Working Group=', I2,
      *      ' Species=', I2, ' Treatment=', I2, ' ACARY(A,F,T)=' ,F9.0/
      *      ' COEFS(A,F,S,1)=' , F7.3, ' COEFS(...,2)=' , F7.3,
      *      ' COEFS(...,3)=' , F7.3, ' C=' , F11.3)

```

```

C      If there's been a thin and a burn, add the capability indexes
C

```

```

C      IF (T .EQ. 4) THEN ! DO THIN AND BURN.
C          CAP(S)= CAP(S) +ACARY(A,F,T) * ( COEFS(A,F,S,1) +
C      *                      COEFS(A,F,S,2) + COEFS(A,F,S,3) )
C          WRITE(*, 896) A, F, S, T, ACARY(A,F,T),
C      *                      COEFS(A,F,S,2), COEFS(A,F,S,3), CAP(S)
C 896  FORMAT(/' Age=', I2, ' Working Group=', I2,
C      *      ' Species=', I2, ' Treatment=', I2,
C      *      ' ACARY(A,F,T)=' ,F9.0,
C      *      ' COEFS(A,F,S,2)=' , F7.3,
C      *      ' COEFS(A,F,S,3)=' , F7.3,
C      *      ' CAP(S)=' , F9.2)

```

```

C      DO 18 TT= 2, 3
C          CAP(S)= CAP(S) +ACARY(A,F,TT) * COEFS(A,F,S,TT)
C      WRITE(*, 899) A, F, S, TT, ACARY(A,F,TT),
C      *                      COEFS(A,F,S,TT), CAP(S)
C 18  CONTINUE

```

```

C      ELSE ! DO STANDARD, OR THIN, OR BURN.
C 19  CAP(S) = CAP(S) + ACARY(A,F,T) * COEFS(A,F,S,T)
C      WRITE(*, 899) A, F, S, T, ACARY(A,F,T),
C      *                      COEFS(A,F,S,T), CAP(S)
C 899  FORMAT(/' Age=', I2, ' Working Group=', I2,
C      *      ' Species=', I2, ' Treatment=', I2,
C      *      ' ACARY(A,F,T)=' ,F9.0, ' COEFS(A,F,S,T)=' , F7.3,
C      *      ' CAP(S)=' , F9.3)

```

```

C      ENDIF

```

```

20  CONTINUE

```

```

C      Calculate the number of animals or pounds per square mile.

```

```

      DENS(S) = ((CAP(S) / TAC) * 640.) + .5
      IF (BUG) WRITE (*,900) S, CAP(S), DENS(S), TAC
900  FORMAT(/' Species=', I2, ' CAP(S)=' , F6.1, ' DENS(S)=' , F6.1,
      *      ' TAC=' , F6.1)

```

```

22  CONTINUE

```

APPENDIX D. (Cont'd.)

IF (BUG) Call Pause

C Sum the acres that have been thinned or burned.

```
DO 205 F = 1, 7      ! for each type
DO 205 A = 1, MAXAGE ! for each age class.
DO 205 T = 2, 4      ! for each treatment.
    IF ( ACARY(A,F,T) .EQ. 0. ) GOTO 205
    ACT(T) = ACT(T) + ACARY(A,F,T)
```

205 CONTINUE

* Calculate WFUDS and stuff

```
*
DO 26 I = 1, 8
    WFDAY(I) = CAP(I) * UDAY(I)
    WFDAY(9) = WFDAY(9) + WFDAY(I)
    PRINT*,I,CAP(I),UDAY(I),WFDAY(I)
C 26 CONTINUE
```

```
DO 28 I = 1, 8
    WFUDVA(I) = WFDAY(I) * RPAVAL(I)
    WFUDVA(9) = WFUDVA(9) + WFUDVA(I)
28 CONTINUE
```

```
!-----!
!           Print it out           !
!-----!
```

```
WRITE (out,103) ANAREA, IST, IFIX(TAC), REPYR, FTSPEC
103 FORMAT(' <FF>', 78('-')/
*      ' HABITAT CAPABILITY FOR ANALYSIS: ', A/
*      ' Number of stands -', I6,' NUMBER OF ACRES - ',I6/
*      ' REPORTING YEAR - ',I6,' FEATURED SPECIES - ',A14/
*      ' ', 78('-')//
*      ' SPECIES           HABITAT CAP      WFUDS'/
*      ' ANIMALS (#/SQ MI)'/
*      ' ', 78('-'))
```

```
DO 30 I=1, 8
    WRITE (out,104) SPECIE(I), IFIX(CAP(I)+0.5), DENS(I),
*      IFIX(WFDAY(I)+0.5)
104 FORMAT (' ',A17,I8,F9.0,I8)
30 CONTINUE
```

```
WRITE (out,105) IFIX(WFUDVA(9)+0.5)
105 FORMAT(' TOTAL $ OF WFUDS = ',I11)
```

```
IF( ELEV .LT. 1200) WRITE (out,106)
106 FORMAT (/' GROUSE ARE LIMITED BY ELEVATION')
```

```
DO 350 T= 1, 4
    IF ( ACT(T) .EQ. 0) GOTO 350
    WRITE (out,109) ACT(T), TMENT(T)
```

APPENDIX D. (Cont'd.)

```

109     FORMAT(/,I5,' ACRES ',A7,' THIS REPORTING PERIOD')
350     CONTINUE

      WRITE (out,115)
115     FORMAT(/' SUMMARY OF ACRES FOR THIS ANALYSIS UNIT:')

      DO 32 F = 1, 7
      DO 32 A = 1, MAXAGE
        DO 320 T = 1, 4
          IF ( ACARY(A,F,T) .GT. 0.) GOTO 327
320      CONTINUE
        GOTO 32
327      WRITE (out,107) FTYPE(F), CLASS(A), ACARY(A,F,T)
107      FORMAT(' ', A14, 2X, A7, F11.0)
32      CONTINUE

      IF (out .EQ. scr) Call Pause

      PRINT *, ' DO YOU WANT TO PRINT ANOTHER REPORTING YEAR (Y/N)? '
      READ(kbd,'(A1)') REPANS

      REPSW=(REPANS.EQ.'Y').OR.(REPANS.EQ.'y')
      IF(.NOT.REPSW) THEN
        PRINT *, '<FF> ALL DONE<004>'
        STOP
      ENDIF

C      ZERO OUT THE SUMS BEFORE DOING THE NEXT REPORTING YEAR.

      FLAG = 1
      IST =1
      TAC =0.
      DO 175 T=1,4
        ACT(T)=0
175     CONTINUE
      DO 40 I=1,17
      DO 40 J=1,7
      DO 40 K=1,4
40      ACARY(I,J,K)=0.
      DO 170 K=1,8
170     CAP(K)=0.
      DO 185 K=1,9
        WFDAY(K)=0.
185     WFUDVA(K)=0.

      CLOSE(10)
      GO TO 5      ! return to perform calculations for new year.

```

* * * * * F O R M A T S * * * * *

```

100     FORMAT ('1')

```

APPENDIX D. (Cont'd.)

```

101  FORMAT (A1)
800  FORMAT (I3,8I4)

C      Define the error references.

820  WRITE(6,822) PFILE
822  FORMAT( '<LF><BEL> ***ERROR - A data file already exists with',
*      ' the name "', A24, '"' )
      PRINT *, '<LF>      Would you like to :   1) Choose a new ',
*      ' area name ? <NL>',
*      ' ',
*      ' file and continue ?'
      PRINT *, ' ', ' or 3) Exit the program ?'
      WRITE(6,*) '<NL>      ENTER 1, 2, OR 3 -- '
821  READ(5,'(I1)') REPLY2
      IF(REPLY2.EQ.1) THEN
          WRITE(6,*) ' Enter new area name : '
          READ(5,'(A24)') ANAREA
          PFILE = ANAREA
          IF(FLAG.EQ.0) GO TO 503      ! for screen data entry
          IF(FLAG.EQ.1) GO TO 501      ! for file data entry
      ENDIF
      IF(REPLY2.EQ.2) THEN
          OPEN(10,FILE=PFILE)
          CLOSE(10, STATUS = 'DELETE')
          IF(FLAG.EQ.0) GO TO 503      ! for screen data entry
          IF(FLAG.EQ.1) GO TO 501      ! for file data entry
      ENDIF
      IF(REPLY2.EQ.3) STOP
      IF(REPLY2.NE.1 .AND. REPLY2.NE.2 .AND. REPLY2.NE.3) THEN
          WRITE(6,*) '<BEL> *****ERROR - ENTER 1, 2, OR 3 -- '
          GO TO 821
      ENDIF

      END      ! End of MAIN program


SUBROUTINE GETAC(ACARY,TP,AC,ACOP,AGE,kbd,WG,TRT,MAXAGE)

COMMON BUG
LOGICAL BUG
IMPLICIT INTEGER( A- Z)
REAL ACARY(17,7,4)
CHARACTER*1 ANS,NO/'N'/

CALL WORKGP(TP,WG)                                !LOCATE THE WORKING GROUP
IF (WG .EQ. 0) RETURN

IF(AGE .LT. 11) THEN                                !DETERMINE THE AGE CLASS
    IF( AGE .LT. 6) THEN
        AGECLS=1
    ELSE
        AGECLS=2
    
```


APPENDIX D. (Cont'd.)

ENDIF

ELSE

AGECLS= (AGE-1) / 10 + 2

IF (AGECLS.GT.MAXAGE) AGECLS=MAXAGE

ENDIF

ACARY(AGECLS,WG,TRT) = ACARY(AGECLS,WG,TRT) + AC

!ASSIGN AC TO

ACARY

C SUM the total acres in this working group.

ACARY(17,WG,1) = ACARY(17,WG,1) + AC

C Sum the acres in openings.

ACARY(16,WG,1) = ACARY(16,WG,1) + ACOP

IF (BUG) Then

Write (*, 10) AGECLS, WG, TRT, AC, ACARY(AGECLS,WG,TRT)

10 FORMAT/' In Sub GETAC for Age Class=', I3,

* ' Working Group=', I3, ' Treatment=', I3/

* ' Adding AC=', I5, ' to ACARY() to get: ', F8.0)

Call Pause

ENDIF

RETURN

END !End of subroutine GETAC

SUBROUTINE WORKGP(F1,F2)

* THIS SUBROUTINE CONVERTS FROM FOREST TYPE OR MANAGEMENT TYPE
* TO WORKING GROUP.

* F1= CISC FOREST TYPE OR MANAGEMENT TYPE

* F2= WORKING GROUP

* =1 (Yellow pine)

* =2 (White pine)

* =3 (Virginia pine)

* =4 (Pine/hardwood or Hardwood/pine mixed)

* =5 (Bottomland hardwood)

* =6 (Cove hardwood)

* =7 (Upland hardwood)

COMMON BUG

LOGICAL BUG

IMPLICIT INTEGER (A - Z)

F2=0

IF (F1.GE.3 .AND. F1.LE.5) F2=2

IF(F1.EQ.32 .OR. F1.EQ.38 .OR. F1.EQ.39 .OR.F1.EQ.31

APPENDIX D. (Cont'd.)

```

*      .OR. F1.EQ.22) F2=1

IF( F1.EQ.58 .OR. F1.EQ.50 .OR. F1.EQ.55 .OR. F1.EQ.56
*      .OR. F1.EQ.41 .OR. F1.EQ.62 .OR. F1.EQ.63
*      .OR. F1.EQ.46 .OR. F1.EQ.64 .OR. F1.EQ.65
*      .OR. F1.EQ.68 .OR. F1.EQ.69 .OR. F1.EQ.71
*      .OR. F1.EQ.72 .OR. F1.EQ.73 .OR. F1.EQ.75
*      .OR. F1.EQ.76 .OR. F1.EQ.61) F2=6

IF(F1.EQ.52 .OR. F1.EQ.53 .OR. F1.EQ.54 .OR. F1.EQ.59
*      .OR. F1.EQ.51 .OR. F1.EQ.82 .OR. F1.EQ.57 .OR.
*      F1.EQ.60 ) F2=7

IF(F1.EQ.33) F2=3

IF ((F1.GE.8 .AND. F1.LE.20) .OR. (F1.GE.40 .AND.
*      F1.LE.49)) F2=4

IF (BUG) Then
  Write ( *, 10)  F1, F2
10  Format(/' Forest Type or Management Type=', I3/
*      ' converts to Working Group      =', I3/)
  Call Pause
ENDIF

RETURN
END      ! End of subroutine WORKGP


SUBROUTINE CISC_ENTER (ID, PREV_COUNT, COUNT2)

C      Written by Kay Berding      July 1987
C      This subroutine allows data in a file called 'CISCnnn'
C      (where 'nnn' is the compartment number) to be used
C      as input to CHHABCAP

  INTEGER I,ST,ID,K,ITEM_NUM,COUNT,COUNT2,FT(100),TAC(100),
*      ACOP(100),BIRTH(100),MT(100),REGYR(100),
*      BRNYR(100),THNYR(100), ANS2, PREV_COUNT, STAND_NUM
  CHARACTER NORY
  CHARACTER*3 CPT
  CHARACTER*7 CISCFILE

C  Define error messages
  CHARACTER*25 ERR_1_2 / '<BEL> ERROR -- ENTER 1 OR 2 - '/
  CHARACTER*25 ERR_N_Y / '<BEL> ERROR -- ENTER Y OR N - '/

C  Initialize acres of wildlife openings, year for burning, and
C  year for thinning to zero.
  COUNT = 0      ! counter for number of stands in this compartment
  DO 4000 I =1,100

```

APPENDIX D. (Cont'd.)

```
ACOP(I) = 0
REGYR(I) = 0
BRNYR(I) = 0
```

4000 CONTINUE

C Read stand data from the CISCnnn file

```
4013 WRITE(6,*) '<ff> Enter compartment number ', ID, ' - '
      READ(5,'(A3)') CPT
      CISCFILE= 'CISC' // CPT
      OPEN(20, FILE=CISCFILE, STATUS='OLD', ERR=4001)
4010 READ(20,4011, END=4012) ST, FT(ST), TAC(ST), BIRTH(ST), MT(ST)
4011 FORMAT(6X, I2, 3X, I3, 2X, I4, 5X, I3, 2X, I3)
      COUNT=COUNT + 1 ! sums number of stands in this compartment
      GO TO 4010

4012 COUNT2 = COUNT2 +COUNT !sums total number of stands in all cpts

      WRITE(6,*) '<LF> Would you like to enter a year of regeneration '
      * , '<LF> for any of the stands in this compartment? '
4017 READ(5,'(A1)') NORY
      IF((NORY.NE.'Y' .AND. NORY.NE.'y').AND.
      * (NORY.NE.'N' .AND. NORY.NE.'n') ) THEN
          WRITE(6,*) ERR_N_Y
          GO TO 4017
      ENDIF
      IF(NORY.EQ.'Y' .OR. NORY.EQ.'y') THEN
          ITEM_NUM = 4
          CALL INFO_ENTER(REGYR, ITEM_NUM, COUNT)
      ENDIF

      WRITE(6,*)
      WRITE(6,*) ' Do any of the stands contain permanent wildlife ',
      * ' openings? '
4014 READ(5,'(A1)') NORY
      IF((NORY.NE.'Y' .AND. NORY.NE.'y').AND.
      * (NORY.NE.'N' .AND. NORY.NE.'n') ) THEN
          WRITE(6,*) ERR_N_Y
          GO TO 4014
      ENDIF
      IF(NORY.EQ.'Y' .OR. NORY.EQ.'y') THEN
          ITEM_NUM = 1
          CALL INFO_ENTER(ACOP, ITEM_NUM, COUNT)
      ENDIF

      WRITE(6,*)
      WRITE(6,*) ' Will any of these stands be burned? '
4015 READ(5,'(A1)') NORY
      IF((NORY.NE.'Y' .AND. NORY.NE.'y').AND.
      * (NORY.NE.'N' .AND. NORY.NE.'n') ) THEN
          WRITE(6,*) ERR_N_Y
          GO TO 4015
      ENDIF
      IF(NORY.EQ.'Y' .OR. NORY.EQ.'y') THEN
          ITEM_NUM = 2
```

APPENDIX D. (Cont'd.)

```
      CALL INFO_ENTER(BRNYR, ITEM_NUM, COUNT)
    ENDIF

    WRITE(6,*)
    WRITE(6,*) ' Will any of these stands be thinned? '
4016  READ(5, '(A1)') NOR_Y
      IF((NOR_Y.NE.'Y' .AND. NOR_Y.NE.'y').AND.
*      (NOR_Y.NE.'N' .AND. NOR_Y.NE.'n') ) THEN
        WRITE(6,*) ERR_N_Y
        GO TO 4016
      ENDIF
      IF(NOR_Y.EQ.'Y' .OR. NOR_Y.EQ.'y') THEN
        ITEM_NUM = 3
        CALL INFO_ENTER(THNYR, ITEM_NUM, COUNT)
      ENDIF

    DO 4020 K= 1,COUNT
      ! Assign a new stand number to correspond with the total
      ! area under consideration.
      STAND_NUM = PREV_COUNT + K
      WRITE(10,801) STAND_NUM, FT(K), TAC(K), ACOP(K), BIRTH(K),
*      MT(K), REGYR(K), BRNYR(K), THNYR(K), CPT, K
801  FORMAT( I3, 8I4, 1X, A3, I4)
      ! The last two items in the data file keep track of the
      ! original compartment and stand numbers.
4020  CONTINUE
      PREV_COUNT = PREV_COUNT + COUNT ! increment the number of
C      stands in previous compartment before entering
C      info for the next compartment
      RETURN

C      Define the error references
4001  WRITE(6,*)
*      ' <BEL>*** ERROR -- NO CISCnnn FILE EXISTS FOR COMPARTMENT ',
*      CPT
      WRITE(6,*) ' Would you like to : '
      WRITE(6,*) '          1) choose a new compartment number?'
      WRITE(6,*) '          or 2) exit the program? '
      WRITE(6,*) ' Enter 1 or 2 -- '
4002  READ(5, '(I1)') ANS2
      IF(ANS2.NE.1 .AND. ANS2.NE.2) THEN
        WRITE(6,*) ERR_1_2
        GO TO 4002
      ENDIF
      IF(ANS2.EQ.1) GO TO 4013
      IF(ANS2.EQ.2) STOP

    END          ! end of subroutine CISC_ENTER
```

SUBROUTINE INFO_ENTER(ITEM, NUM, COUNT)

APPENDIX D. (Cont'd.)

```
INTEGER ITEM(100), INDX, FORM_NUM, ST, NUM, I, COUNT

CHARACTER*36 FORMATS(4)
FORMATS(1) = 'number of acres in wildlife openings'
FORMATS(2) = 'year for burning      (xxxx)'
FORMATS(3) = 'year for thinning     (xxxx)'
FORMATS(4) = 'year of regeneration (xxxx)'

5002  WRITE(6,*) ' How many stands? '
      READ(5,*) INDX
      IF(INDX.GT.COUNT) THEN
        PRINT *, '<bel> *** There are only ',count, ' stands in this '
        *      , 'compartment ***<nl>      Please correct the ',
        *      'number --<NL>'
        GO TO 5002
      ENDIF
      DO 5001 I = 1, INDX
5003  WRITE(6,*) ' Enter stand number ', I, ' - '
      READ(5,*) ST
      IF(ST.LE.0 .OR. ST.GT.COUNT) THEN
        PRINT *, '<BEL> No stand # ', ST, ' exists.<nl> Please ',
        *      'correct the stand number --<nl>'
        GO TO 5003
      ENDIF
      WRITE(6,5100) FORMATS(NUM)
      READ(5,*) ITEM(ST)
5001  CONTINUE

C      ***** FORMAT STATEMENTS *****
5100  FORMAT(' Enter the ',A36, ' : ')

      RETURN
      END          !end of subroutine INFO_ENTER
```

Subroutine Pause

```
Character*1 ANS
! The 016 and 017 cause BLINK on and off.
PRINT *, '<NL><016>PRESS NEWLINE TO CONTINUE<017> '
READ (*, '(A1)') ANS
If (ANS.EQ.'Q' .OR. ANS.EQ.'q') STOP

RETURN
END
```

Subroutine TITLE

! Prints the title page.

```
PRINT *, '<14><003>'
PRINT *, '
```

CH - H A B C A P 4

APPENDIX D. (Cont'd.)

```
PRINT *, ' <BEL>'
PRINT *, 'This program uses Region 8 coefficients to calculate ',
* 'habitat capability'
PRINT *, 'expressed as numbers of animals for management ',
* 'indicator species. It uses'
PRINT *, 'regional information to convert animal capability to ',
* 'WFUD's and dollar '
PRINT *, 'values. '
PRINT *
PRINT *
PRINT *, 'If existing data is to be used, the user must ',
* 'specify the file name'
PRINT *, 'as either: 1) a file containing CISC data or 2) ',
* 'the area name.'
PRINT *
PRINT *, 'If no data exists, the user must specify the number ',
* 'of stands in'
PRINT *, 'the analysis unit and the following data for each stand : '
PRINT *, 'forest type, acres, inclusion acres, birthdate, '
PRINT *, 'management type, year to regenerate, year to thin, ',
* 'and year to burn.'
PRINT *
PRINT *, 'The user must specify the reporting year and average ',
* 'elevation for the area.'
PRINT *, 'The individual stand data will automatically be written ',
* 'to a file with '
PRINT *, 'the same name as the user-specified area name.'
Call Pause

RETURN
END
```

! End of Source Listing !

APPENDIX E. Index to abbreviations used in appendices

Abbreviations used in Appendix A

AA NO - Analysis area number
RG PD - Regeneration period
STD NO - Stand number
LAND CLASS - Land classification code
FOR TYPE - Forest type code
ST CC - Stand condition class code
ACRES - Acres included within the stand
MOC - Method of cut (type of harvest cut) code
AGE YRS - Age of the stand in years
WL - Wildlife species emphasized (code no longer used)
CISC MGTP - Management type code as recorded in CISC database
LMP MGTP - Land management plan management type if different from CISC type
SI MT - Site index for the management type
PC FT -
REG METH - Recommended regeneration method
THIN - Thinning recommended - Yes or No
TOT CCF /ACRE - Total volume of pole timber measured in hundreds of cubic feet (CCF) per acre
SAW MBF /ACRE - Total volume of sawtimber measured in thousands of board feet (MBF) per acre
MA NO - Management area number
STNDS - Number of stands

Abbreviations used in Appendix B

ALT A - Alternative A
ST # - Stand number
Trt Ac - Acres within this stand to be treated
YL POP - Yellow poplar (*Populus deltoides*)
WH O - White Oak (*Quercus alba*)
NR O - Northern Red Oak (*Quercus nigra*)
HK - Hickory (*Carya* spp.)
NATL - Natural
Cand Ac regen - Acres of regeneration included on the candidate stand list
Non-cand regen - Acres of regeneration not included on the candidate stand list
% Non-cand regen - Percent of regeneration acres not on candidate stand list
Net Change Hdws - Net acres that would be converted from hardwood in each alternative
an/sqmi - Habitat capability for each species expressed in animals per square mile
pds/ac - Pounds per acre
dens/sqmi - Dens per square mile
TMBR YLDS- REGN (vol) - Timber yields from regeneration
Hdwd STMBF - Hardwood sawtimber in "thousand board feet" (MBF)
Hdwd RWCCF - Hardwood roundwood in "hundred cubic feet" (CCF)
CULTURAL TRT COSTS - Cultural treatment costs
Sales Prep & Harv Ad - Sale Preparation and Harvest Administration costs
SP for Clearcut - Sale preparation for clearcutting costs
Total Tbr - Total timber costs
Total- 1st Pd Rd+ Tbr - Total costs for the first period road use plus timber costs
S/C (Sales Prep + HA) - Stumpage/Cost ratio where cost includes sale preparation plus Harvest Administration costs
S/C (SP + HA + Est) - Stumpage/Cost ratio where cost includes sale preparation, Harvest Administration, and stand establishment costs

Abbreviations used in Appendix B (Cont'd.)

S/C (SP+HA+Est+Rd-1) - Stumpage/Cost ratio where cost includes sale preparation, Harvest Administration, stand establishment, and the first period road use costs

Abbreviations used in Appendix C

CHHABCAP - CHattahoochee HABitat CAPability computer program

WFUDS - Wildlife and Fish User Days

LITERATURE CITED

- Boyce, S. 1980. Management of forests for optimal benefits (DYNAST-OB). USDA For. Serv. SE For. Exp. Sta., Asheville, N.C. Research Paper SE-204. 92 p.
- Brand, G.J., S.R. Shifley, and L.F. Ohmann. 1986. Linking wildlife and vegetation models to forecast the effects of management. *In Proc. Symp. on Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates*, October 7-11, 1984, Fallen Leaf Lake, Cal. J. Verner, M.L. Morrison, and C.J. Ralph (editors). Univ. Wis. Press, Madison, Wis., pp. 383-388.
- Brown, E.R. (technical editor). 1985. Management of wildlife and fish habitats in forests of western Oregon and Washington. USDA For. Serv., Pac. NW Reg. Portland, Ore. 2 vols. Publ. R6-F&WL-192-1985. 634 p.
- Holthausen, R.S. 1986. Use of vegetation projection models for management problems. *In Proc. Symp. on Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates*, October 7-11, 1984, Fallen Leaf Lake, Cal. J. Verner, M.L. Morrison, and C.J. Ralph (editors). Univ. Wis. Press, Madison, Wis., pp. 371-376.
- Hoover, R.L. and D.L. Wills (editors). 1984. Managing forested lands for wildlife. Col. Division of Wildl., Denver, Col. 459 p.
- Kirkman, R.L., J.A. Eberly, W.R. Porath, and R.R. Titus. 1986. A process for integrating wildlife needs into forest management planning. *In Proc. Symp. on Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates*, October 7-11, 1984, Fallen Leaf Lake, Cal. J. Verner, M.L. Morrison, and C.J. Ralph (editors). Univ. Wis. Press, Madison, Wis., pp. 347-350.
- Moeur, M. 1986. Predicting canopy cover and shrub cover with the Prognosis-COVER model. *In Proc. Symp. on Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates*, October 7-11, 1984, Fallen Leaf Lake, Cal. J. Verner, M.L. Morrison, and C.J. Ralph (editors). Univ. Wis. Press, Madison, Wis., pp. 339-346.
- Thomas, J.W. (editor). 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. USDA For. Serv., Portland, Ore. Agric. Handb. 553. 512 p.



3



Managing for Wildlife Diversity in Forested Watersheds in British Columbia: The Wildlife Habitat Handbook

Andrew P. Harcombe
Ministry of Environment, Lands and Parks
Wildlife Branch
810 Blanshard Street
Victoria, B.C.
V8V 1X5

PREFACE

This paper describes the attempt to develop tools for managing wildlife diversity in British Columbia. The example used is primarily for watershed-level projects, although the system is relevant to other levels of resource planning. This project has generally been referred to as the Wildlife Habitat Handbook program, jointly sponsored by Ministry of Environment, Lands, and Parks, Ministry of Forests, University of British Columbia, Simon Fraser University, Royal British Columbia Museum, and the Canadian Wildlife Service, with additional funding from Wildlife Habitat Canada. Much of the handbook approach is derived from wildlife habitat work that has been carried out in the National Forest system in the United States (e.g., Thomas 1979; Hoover and Willis 1984).

The original presentation, given at the 1989 Habitat Futures Conference, included a section on proposed guidelines being developed by the U.S. Forest Service (Lisa Norris), and a section on the selection of indicator species (Peter Landres and Charles Meslow). The former section had been included as an example of what was needed in order to use such tools as the Wildlife Habitat Handbook, and the latter section had been included to describe some pitfalls in selecting species to act as the focus for analyzing management actions. Both are excluded in the final edition to shorten the paper and allow a stronger focus on the B.C. project.

TABLE OF CONTENTS

PREFACE	62
1 THE ISSUE: DEVELOPING A WILDLIFE DIVERSITY MANAGEMENT SYSTEM FOR BRITISH COLUMBIA	64
1.1 Background	64
1.2 Diversity of the Resources	65
1.3 Historical Perspective and Recent Progress	67
1.4 Problems and Risks	67
1.5 The Needed Tools	69
2 CASE EXAMPLE OF THE WILDLIFE DIVERSITY SYSTEM	70
2.1 Introduction to the Management Tools	70
2.1.1 Species notes	73
2.1.2 Habitat evaluation—structure of models	75
2.1.3 Habitat database	77
2.1.4 Habitat evaluation—analysis framework	77
2.2 Utilization of the System	79
2.3 Questions	79
LITERATURE CITED	80

FIGURES

1. Ecoprovinces of British Columbia	65
2. Percentages of Canadian wildlife species found in British Columbia	66
3. Wildlife species evaluation and categorization in British Columbia	68
4. Location of the Southern Interior ecoprovince	71
5. Structural divisions of a model in upland and wetland habitats	72
6. Structural divisions of a model in man-influenced habitats	72
7. Structural divisions of a model in aquatic habitats	73
8. Example of a species note: mountain goat	73
9. Example of a distribution map: mountain goat	74
10. Sample of a table showing relative abundance, by season and habitat, for a species: mountain goat	75
11. Sample of a species—habitat relationship model: mountain goat	76
12. Samples of species density—optimum habitat area values	78
13. Sample output, in projected population numbers, for two alternative management scenarios	78

TABLE

1. Suitability coefficients and their definitions	76
---	----

1 THE ISSUE: DEVELOPING A WILDLIFE DIVERSITY MANAGEMENT SYSTEM FOR BRITISH COLUMBIA

1.1 Background

The value of a diverse and dynamic wildlife resource goes beyond economics and sentimentality. We, as resource managers, have a stewardship or moral obligation to manage wildlife wisely. Wildlife plays a key role in ensuring ecological sustainability. Thus, an approach to management that will encompass diversity of wildlife and their habitats will provide a firm support for ensuring healthy ecosystems and pursuing sustainable development for the future. Diversity can be defined simply as the richness and diversity of life within a geographic area (e.g., stand, watershed, ecoprovince).¹ Wildlife habitat diversity is created by the abundance and arrangement of different plant communities and geographic features within a specific area, thereby providing habitat structure for a variety of wildlife species. Maintaining a variety of wildlife habitats ensures species richness and promotes population stability. Wildlife habitat diversity is also a key factor in maintaining viable populations of wildlife (Brown 1985).

The mission of B.C. Environment's wildlife program is to maintain an optimum balance between ecological, cultural, economic, and recreational needs of modern society. The wildlife program has recently compiled a set of goals and objectives that better identify the concern for ecological sustainability of wildlife and their habitats; these will undergo public and political scrutiny as part of the Provincial Wildlife Strategy (presently in review). The principal goals of the wildlife management program are:

1. to maintain and enhance wildlife and their habitats to ensure an abundant, diverse, and self-sustaining wildlife resource throughout British Columbia;
2. to maintain, enhance, and promote viewing and appreciation of wildlife in their habitats;
3. to maintain, enhance, and promote recreational opportunities to hunt game species in their habitats;
4. to facilitate commercial uses of wildlife; and
5. to protect people and their properties from intolerable levels of danger, damage, or harassment by wildlife.

A promising approach for providing information to managers interested in managing for wildlife diversity is being produced by the Wildlife Fish Habitat Relationship (WFHR) program in the National Forests of the United States. The Wildlife Habitat Handbook program was initiated several years ago in British Columbia, following these American efforts, to provide provincial managers with the capability to make better analyses and decisions in meeting objectives for wildlife diversity through the application of species-habitat tools.

One such effort is the primary focus of the Wildlife Habitat Handbook program. This is a package of "tools" that can be used to analyze the impact of habitat change on a selection of wildlife species, specifically at a watershed or subregional scale. Guiding principles for this project are that it must:

- be easy to use
- be based on existing information
- consider all wildlife species
- consider all essential habitat requirements for species
- be linked to current inventories of forest resources
- be useable by forest and habitat managers
- be computer-based and available in Ministry of Environment, Lands and Parks regions and Ministry of Forests regions and districts

¹ Salwasser, H. 1986. Forest diversity: don't leave the forest without it! *In* Habitat Futures. B.C. Min. For., Victoria, B.C. Draft report.

- ## 1.2 Diversity of the Resources

A map of Canada illustrating its major physical features and climate regions. The map is divided into several climate regions by thick black lines: Northern Boreal, Taiga Plains, Boreal Mountains, Boreal Plains, Sub-Boreal Interior, Southern Interior, Central Interior, Coast and Mountains, Northeast Pacific, and Southern Interior Mountains. Major cities are marked with dots and labeled, including Atlin, Cassiar, Fort Nelson, Port St John, Dawson Creek, Mackenzie, Prince George, Kamloops, Revelstoke, Nelson, Cranbrook, Trail, Kelowna, Vernon, Penticton, Okanagan, Port Hardy, Port Alberni, and Victoria. The Great Depression is labeled in the southwest. The map also shows the Atlantic Ocean, the Gulf of St. Lawrence, and the St. Lawrence River.

65

The vertebrate fauna is composed of at least 1081 species, including 451 fishes, 19 reptiles, 20 amphibians, 448 birds, and 143 mammals (Cannings and Harcombe 1990). The majority of the latter four classes are nonmarine, with a strong affinity to terrestrial systems and forested land. Many of our species are not found in other parts of Canada (Figure 2). In addition to using wildlife for recreational and commercial purposes, British Columbians benefit from its presence, whether or not they encounter animals in the field. It is part of our heritage, and its existence adds to the variety and richness of citizens' lives. It is evident that British Columbia's wildlife heritage is highly valued and extensively used. Wildlife not only enhances the everyday life of most residents, but is a vital contributor to the economic health of the provincial economy.

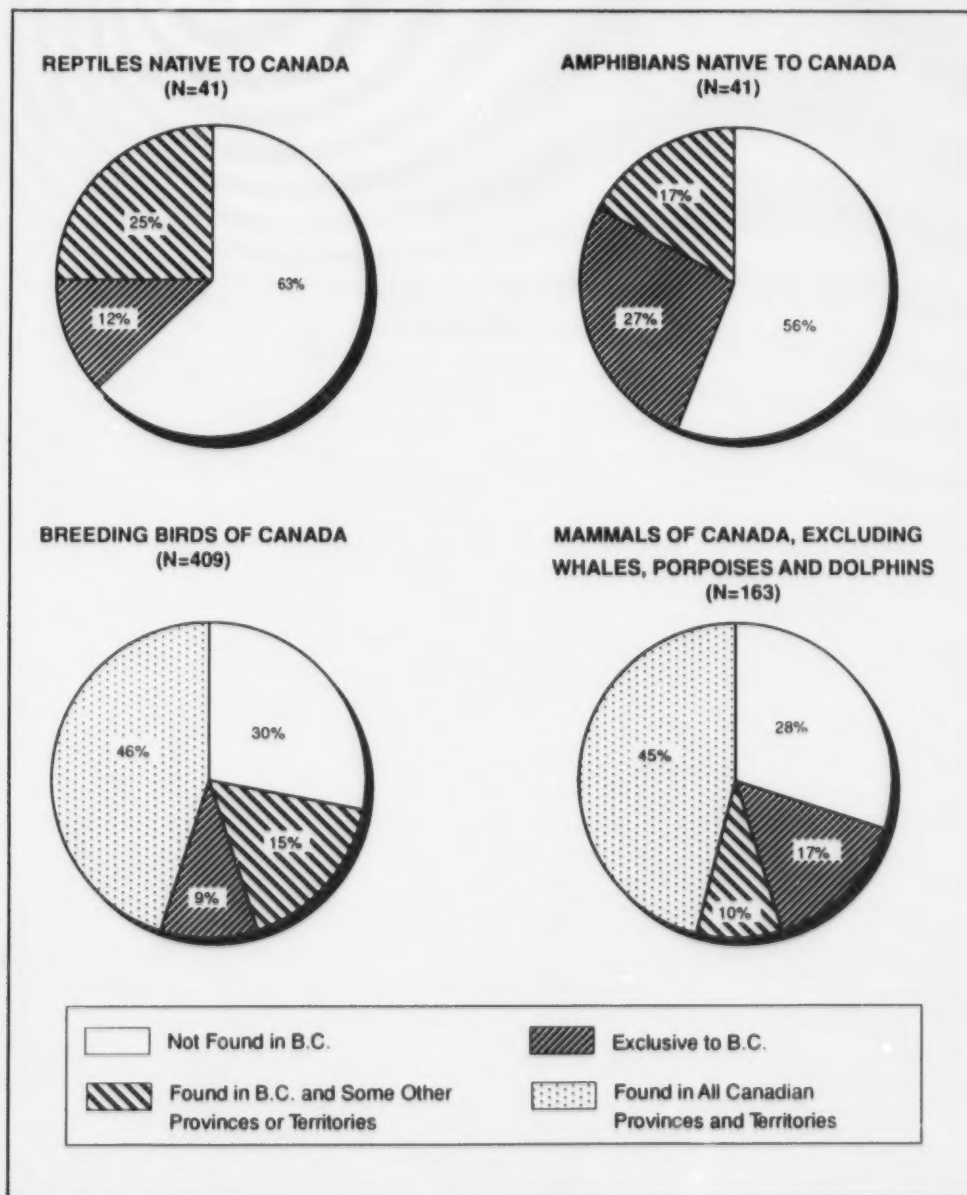


FIGURE 2. Percentages of Canadian wildlife species found in British Columbia.

1.3 Historical Perspective and Recent Progress

There are concerns about diversity in British Columbia because there are weaknesses inhibiting our progress in achieving our primary goal. This is reflected by such things as a poor prognosis for the long-term health of many wildlife populations (B.C. Wildlife Branch 1991) and the increasing awareness of public pressures to actively manage for a greater variety of wildlife. Although British Columbia has no legislation that mandates that diversity concerns must be considered in land management plans, wildlife managers are resolving a number of these weaknesses, concurrently with the development of planning tools, with the hope that diversity planning and management can become a reality.

The legislative mandate for managing wildlife and habitat is divided primarily among three ministries. The management of wildlife is the mandate of the Ministry of Environment, Lands and Parks (MOELP). The responsibility for management of the habitat (i.e., lands and vegetation) is divided between the Ministries of Forests and the Lands part of MOELP. These two provincial ministries have this mandate over most of the provincially owned land base (about 93% of the province). The Ministry of Forests has the major role in multiple resource decisions affecting land use. The planning process is supposed to coordinate and integrate other natural resource values such as fish and wildlife with forest and range resources. British Columbia Lands has a primary orientation to single land use.

A recent process has categorized all terrestrial vertebrates for management purposes, based on a variable ranking system, using such criteria as abundance, distribution, habitat integrity, population trend, reproductive potential, and national and international status. The first subdivision is for species considered to be at risk and those not considered to be at risk (Figure 3). Based on their rarity, species at risk were then subdivided into those that should be considered for designation as threatened and endangered (red list) and those that are considered sensitive or vulnerable (blue list). The species that are not at risk were categorized as those with management emphasis on the species (yellow list) or on the habitat (green list). These four lists help in prioritizing species that should be considered in various management options.

Because of the need for a provincial-level approach to defining ecologically based areas for developing management strategies and diversity objectives, a system of ecoregion classification has been drawn up (Demarchi *et al.* 1990). Large units of land (ecoregions) are delineated, representing areas of similar climatic processes, physiography, and vegetation and wildlife potential. Vegetation (biogeoclimatic) zones are used to delineate vertical variation within the ecoregion units. This system provides a logical way of subdividing the province into geographical units that would contain similar wildlife management strategies and similar wildlife-habitat relationships.

Broad habitat classes have been described for the entire province, including upland, wetland, aquatic, and man-influenced habitats. These in turn can be subdivided by more detail of site features, such as moisture, nutrient regime, slope, and aspect. This habitat classification, in concert with the ecoregion hierarchy, allows information on wildlife species and their habitat requirements to be correctly used in areas for which they have validity.

Historically, wildlife management in British Columbia had an emphasis on regulating the use of game and fur species. Little concern was paid to wildlife habitat until the 1970's. There was no clear understanding of the importance of healthy habitats to viable animal populations. Most research was carried out with game species, so most nongame species were ignored or thought to be alright as long as game populations were healthy. Attitudes have now improved. Industry has been brought into cooperative ventures. Now, the development of wildlife-timber tools has the potential to be useful in achieving resource objectives. At present, British Columbia's program for diversity management is aimed at providing adequate habitat to support viable populations of all wildlife species within their historical areas.

Now that wildlife diversity is the acknowledged primary goal of the wildlife program, the issue of concern for the Wildlife Habitat Handbook program is to develop a system, with appropriate tools, to help plan for this diversity.

1.4 Problems and Risks

The scale of diversity analysis will affect the management objectives, but the components of the tool should remain relatively constant. Therefore, at regional scales (e.g., Timber Supply Area [TSA] and Tree Farm

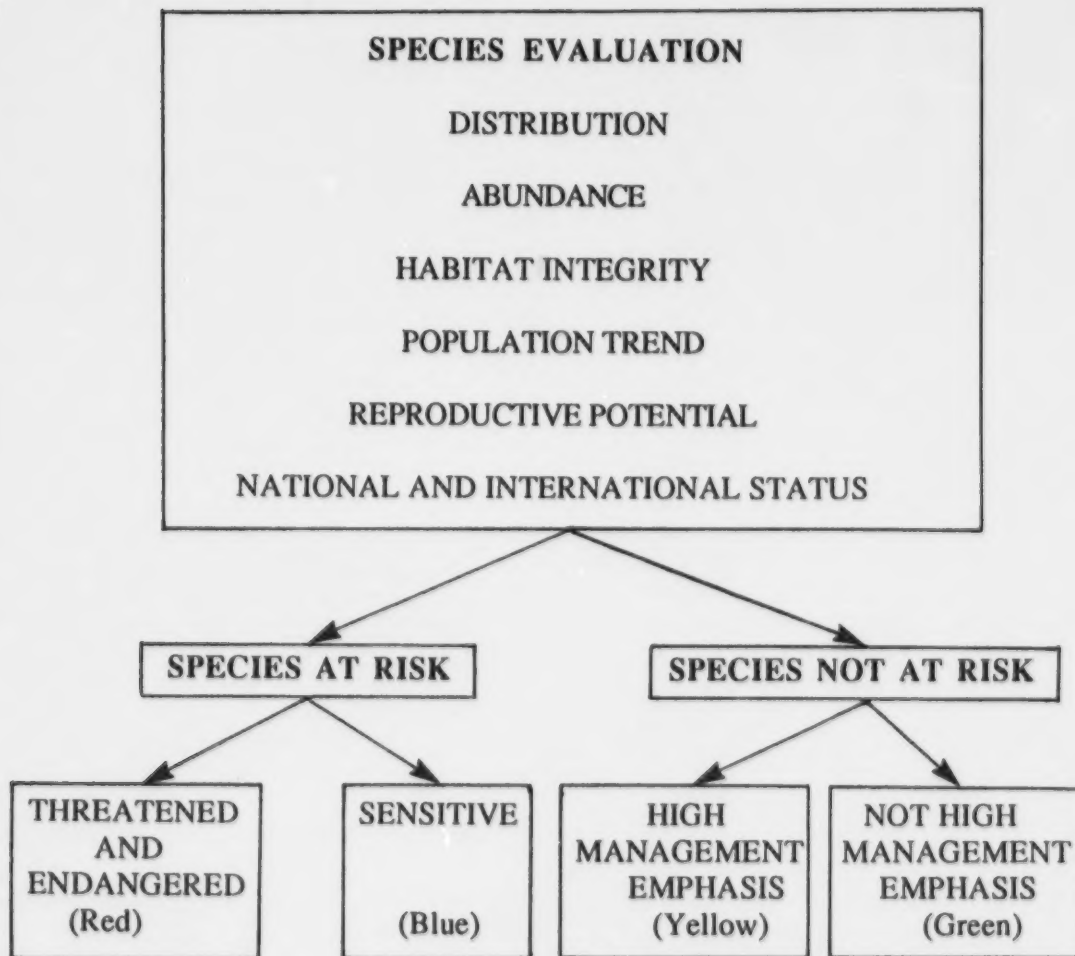


FIGURE 3. Wildlife species evaluation and categorization in British Columbia.

Licence [TFL]) one would be concerned about impacts of habitat requirements that might have a significant implication to the amount of timber available for cutting. At the watershed level, one would be more concerned with the location, pattern, and scheduling of habitat prescriptions, possibly for only a subset of wildlife species. At the forest stand level, one would be most concerned with such attributes as cutblock size and shape, impact of edge, and specific habitat elements (e.g., snags, downed material), and obviously, an even smaller number of wildlife species. The specifics of the development of a forest wildlife diversity management tool that can address the present and future suitability of habitat for a defined area and for a defined set of species will be discussed later in this paper.

For any planning unit there is the problem of setting wildlife objectives that follow direction from higher levels of the planning process, from overview to strategic direction. Decisions made at the regional level need to be carried down to subsequent planning levels, maintaining ties to specific geographic cells where decisions are made. This in turn will allow local resource area planning (e.g., watershed level) to more easily define relevant objectives for supply of all resources. This involves the selection both of wildlife species whose habitat requirements will be considered and of the needed population levels required for some form of long-term survival of the population (i.e., of population viability). Guidelines for setting diversity objectives must be addressed to make a subregional analysis relevant to a broader management program.

The major risk in the whole issue of assessing wildlife values for a planning area is related to the reliability of the models in predicting changing animal response to changing habitat structure. If the critical factors that a species responds to are not a part of the habitat attributes used in the models, then the models' predictive accuracy will be low. There is a risk that the model will not be sensitive enough to identify a significant change in suitability caused by habitat change.

Sophistication is needed at the management level. There must be a suitable selection of species, one that considers the described problems with management indicator species. This selection must reflect higher planning decisions. There must be adequate objectives set in terms of desired products for the watershed. Finally, the tool results must be professionally interpreted by biologists and translated into guidelines for subsequent management actions. The most difficult task will be attempting to provide for a diverse set of wildlife that have very diverse habitat needs. Each watershed cannot provide everything; hence, diversity objectives must be set for the ecoprovince and translated for the TSA or TFL.

The risk of not using these models is the risk of failing to address the program's primary goal by any means other than "good timber management will be good wildlife management." Sufficient reliability is a difficult concept to measure. Model structure has been evaluated by the recognized experts, who have assessed the probability of the model predictions being correct. If the models then give results that a professional biologist would deem possible, then the models are probably reliable enough for the first cut. They can be improved as our knowledge improves; they are not set in stone. Direct field validation is very expensive and time consuming. Much of the benefit of using a diversity management system is its attempt to consider a variety of species beyond those traditionally considered. The tool framework can be used with more detailed models if necessary, to better predict population densities for meeting population objectives. Geographic Information Systems (GIS) is a critical tool in allowing easier assessment and manipulation of mapped data and production of interpretive products. The Wildlife Habitat Handbook approach is used extensively in the National Forests of the United States; forest biologists and managers are using these tools to build diversity criteria into their forest plans, as they are legally mandated to do. For the first attempt, they are certainly superior to ignoring the majority of species. Models are meant to mimic reality; if we perceive that they do a good job, then we will make use of them.

1.5 The Needed Tools

The wildlife manager needs a tool that:

1. can be related to other resource inventories (e.g., forest cover)
2. can show trend changes in suitability of a planning unit (e.g., the watershed of 20000 ha) for a particular species
3. can provide the opportunity to assess a planning unit for all species of wildlife
4. can translate suitability into population density potentials

The tool should be based on an organized set of knowledge about the relative capabilities of different environments or habitats to support wildlife. It should contain models that help predict consequences of contemplated forest management on wildlife, but not provide rigid guidelines. These models, however, should be in a form that does not require the manager to spend a long period of time hand-coloring maps, compiling total areas of each habitat, looking up models in a large book, or doing innumerable calculations

by hand. The species-habitat models need to be linked in a system to an automatic compilation of kinds and relative amounts of wildlife habitats, so that one must only select "species of interest" and "area of interest" to perform an assessment on present habitat suitability. It would be best if the habitat could be made to "grow" over successional time intervals, so when management scenarios were superimposed, consequences based on changing habitat suitabilities would result. Results should be in suitability values, illustrated in both tabular and graphical formats, and in a translation of suitability value into population estimates. Obvious benefits would include rapidity of analysis and ease of application.

Species-habitat models range in complexity from simple coefficients linked to habitat units to highly complex models incorporating individual site attributes, cumulative effects, and pattern attributes (e.g., interspersions, distance to x). Habitat units may be very broad (e.g., coniferous forest) to very detailed (e.g., south aspect, steep colluvial blanket with Douglas-fir — saskatoon — pinegrass ecosystem association). As complexity increases, so do costs and difficulty of use. When habitats are subdivided, subdivisions may be described in terms of structure or floristic composition. The latter can result in several alternatives for each successional stage; however, early successional vegetation is often hard to predict. The more complex the subdivisions, the harder it is to map or identify the habitat units. The recent advent of PC-based Geographic Information Systems (GIS's) has led to a major advance in technical support for map products. If habitat units can be mapped or correlated to existing mapped units (i.e., through "crosswalk" or look-up tables), GIS becomes a means of compiling the habitat inventory. A major problem in British Columbia is the incomplete status of digitized databases and the cost of GIS hardware and software.

2 CASE EXAMPLE OF THE WILDLIFE DIVERSITY SYSTEM

2.1 Introduction to the Management Tools

The wildlife diversity management tool for British Columbia will be a computerized analytical framework for compiling types and amounts of habitat in a planning area, linking this matrix of values to selected species requirements (in the form of simple species-habitat relationship models), and producing habitat suitability values that can be translated into potential population densities. When habitat is modified by either succession or management practice, the system will derive a changed set of habitat suitability values.

The tool is intended to be used by either a forester or a biologist. However, the interpretation of the results and their relationship to meeting diversity objectives for the planning area must be done by the professional biologist. The system is intended to provide a tool for evaluation and understanding, not to design a set of guidelines for the land manager. All species are potentially available in the analysis. However, those that are either rare or require large home ranges will not give reasonable results.

The production of this tool requires that:

1. the information base be compiled (species notes and habitat classification)
2. a habitat evaluation system be developed (models)
3. the technological decisions for tying the system components together be made
4. a user-friendly software package be produced, with a user guide

Steps 1, 2, and 3 have been completed (Harcombe 1988; Harcombe *et al.* 1992). Step 4 is a draft form.

The prototype system can be demonstrated for a 24000-ha watershed for the Louis Creek valley, northeast of Kamloops in the Southern Interior Ecoprovince (Figure 4). This ecoprovince has the warmest, driest summers, with air moving in from the west being dried by orographic subsistence. Surface heating results in frequent showers. Major valleys provide areas of higher surface temperatures, enhanced convective currents, and sources of readily available moisture. Hot dry air from the Great Basin (United States) may come into the area, bringing clear skies and very warm temperatures. In winter, infrequent outbreaks of cold arctic air fill the valleys.

This ecoprovince is an area dominated by the Interior Plateau, with low to moderate relief in the form of basins, plateaus, and highlands. Most of the plateau is between 1200 and 2000 m elevation. It is dissected by the Thompson River and its tributaries, and by the Similkameen and Okanagan Rivers (tributary to the Columbia River).

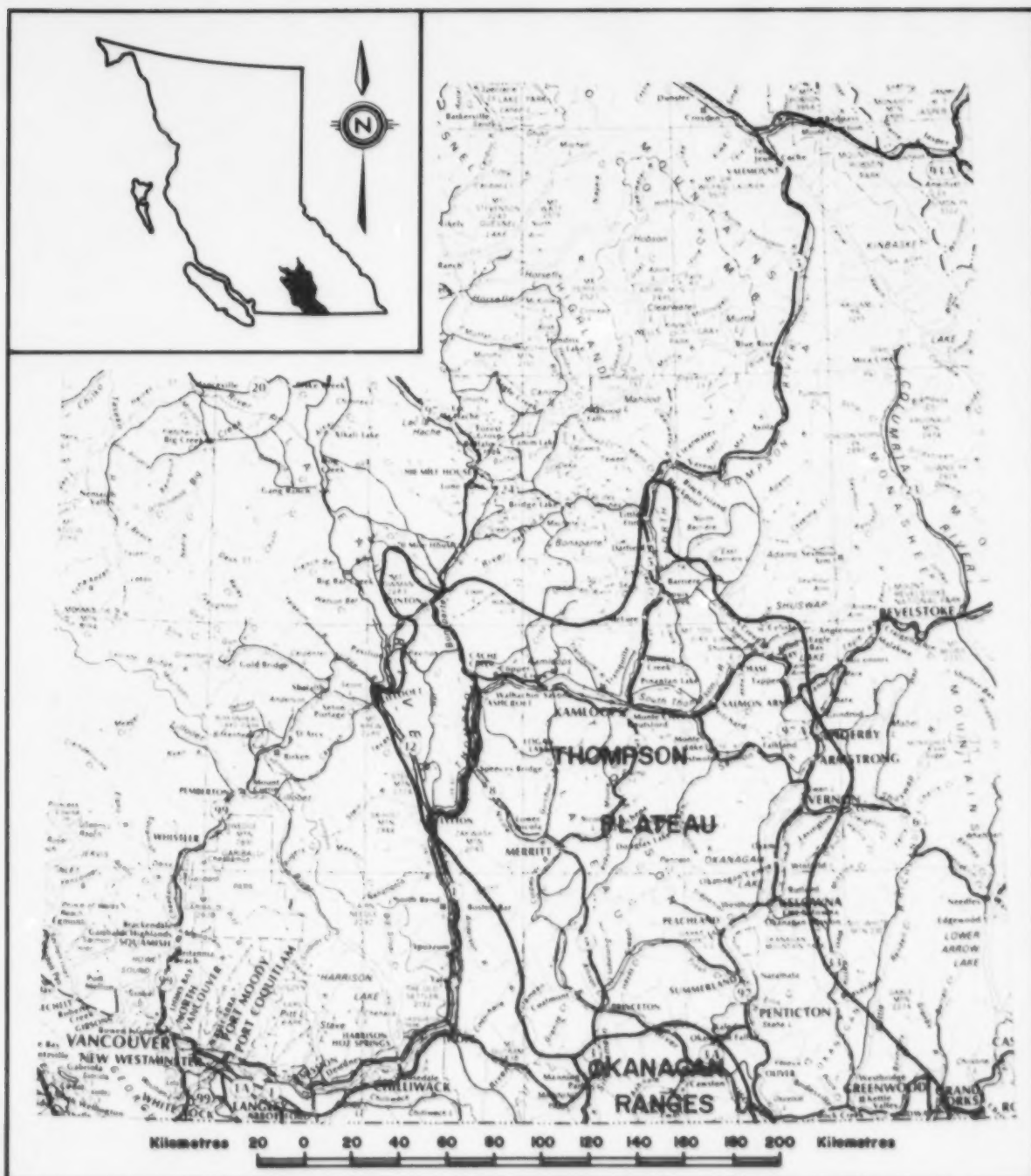


FIGURE 4. Location of the Southern Interior ecoprovince.

The Southern Interior ecoprovince supports a diversity of upland and aquatic habitats, varying from open grasslands to dense, coniferous forests, and from small alkaline ponds to large, deep lakes. Vegetation zones go from grassland through coniferous forest to alpine tundra. The habitat classification is divided into four major groups: upland (terrestrial) habitats (12), wetland (palustrine) habitats (5), aquatic (deepwater) habitats (3), and man-influenced (agricultural or urban) habitats (4). The upland and wetland habitats were subdivided by up to six successional or structural classes and these were further subdivided into up to three canopy closure classes (see Figure 5). The aquatic habitats were subdivided by aquatic type (e.g., marine, freshwater), aquatic (flooding) zones (e.g., deep water, shallow, shore), and substrate type (e.g., rock, unconsolidated, aquatic bed of vegetation) (see Figure 6). The man-influenced habitats, strongly influenced by human activity for a long time, were structurally subdivided when applicable (see Figure 7). Special elements were added so that critical components of some wildlife species requirements were not overlooked. These elements are generally too small to be mapped, and are not necessarily implied by the habitat class designation. They include cliffs, caves, snags, down materials, deciduous trees, and man-made elements. Because the manipulation of some of these elements is easy, they are very important to consider, lending critical diversity to the landscape.

FIGURE 5. Structural divisions of a model in upland and wetland habitats.

FIGURE 6. Structural divisions of a model in man-influenced habitats.

Name of Habitat		
Season to be Rated		
Types of Uses for which each Habitat will be Rated	P o n d	Aquatic Zones
		Substrate Types

FIGURE 7. Structural divisions of a model in aquatic habitats.

2.1.1 Species notes

Species notes are the compilation of known literature information about the habitat requirements of vertebrate species. This requirement information has been subdivided by major life function or requisite, as feeding, reproduction, and special needs (escape, hiding cover, migration areas, cover from climatic extremes). They were compiled from species experts, and include additional source references for more detailed data. They have been prepared for all the mammals, reptiles, and amphibians found in the ecoprovince, and for 55 selected birds (a sample note is shown in Figure 8). A distribution map for the province is also provided (Figure 9). Information was compiled at a provincial scale, to avoid the necessity of repeating the exercise for other ecoprovinces.

Mountain Goat ORAM *Oreamnos americanus* [de Blainville]

Distribution, Seasonality and Abundance

Distributed throughout suitable habitats on the mainland of British Columbia. Most abundant in Rocky Mountains, scattered coastal mountain populations, and northern mountains and plateaus. Native yearlong residents.

Habitat Requirements - Reproduction

HABITAT CLASSES: Widespread habitat use for breeding. Birth areas in a variety of habitats ranging from coastal Douglas-fir - western hemlock and boreal spruce forests to alpine tundra, more dependent upon suitability of terrain than vegetation class.

SPECIFIC HABITAT ELEMENTS: Rocky cliffs or boulders.

Habitat Requirements - Feeding

HABITAT CLASSES: Select habitat more for its topographical features than for available forage. Feed in a variety of habitats adjacent to cliffy areas such as alpine tundra, alpine, subalpine wet meadows, coastal subalpine parkland, interior subalpine parkland, talus shrublands, and subalpine forest burns. Goats may feed in lower coniferous forests during winter in wet snow areas, or may use windswept ridges in dry interior locations.

SPECIFIC HABITAT ELEMENTS: Generalist herbivores. Interior summer diet primarily graminoids, while coastal goats eat shrubs with lesser amounts of graminoids. Winter diet mainly twigs of shrubs and trees

and both arboreal and terrestrial lichens. May travel outside usual spring or summer home range to mineral licks.

Habitat Requirements - Special Needs

SPECIFIC HABITAT ELEMENTS: Use rocky cliffs as escape terrain. Variety of microclimates desirable for thermoregulation, including snow or ice, steep forested areas, north- and south-facing rocky bedding sites, and feeding sites.

Habitat Requirements - Pasture

Important to have good foraging sites adjacent to rocky cliff areas, especially for mothers and kids in early summer. Coastal populations usually require close proximity winter range.

Activity and Movement Patterns

Diurnal, with avoidance of direct solar radiation during hot periods in summer. Active all year. Local migrators, especially in coastal populations.

Status

Not in jeopardy. Protected as big game under the British Columbia Wildlife Act (1982).

Selected References

Chadwick 1978; Cowan and McCrory 1970; Foster 1964; Hebert and Turbill 1977; Hjeljord 1971; Stevens 1983.

FIGURE 8. Example of a species note: mountain goat (Stevens and Loftis 1988, p 144).

Mountain Goat

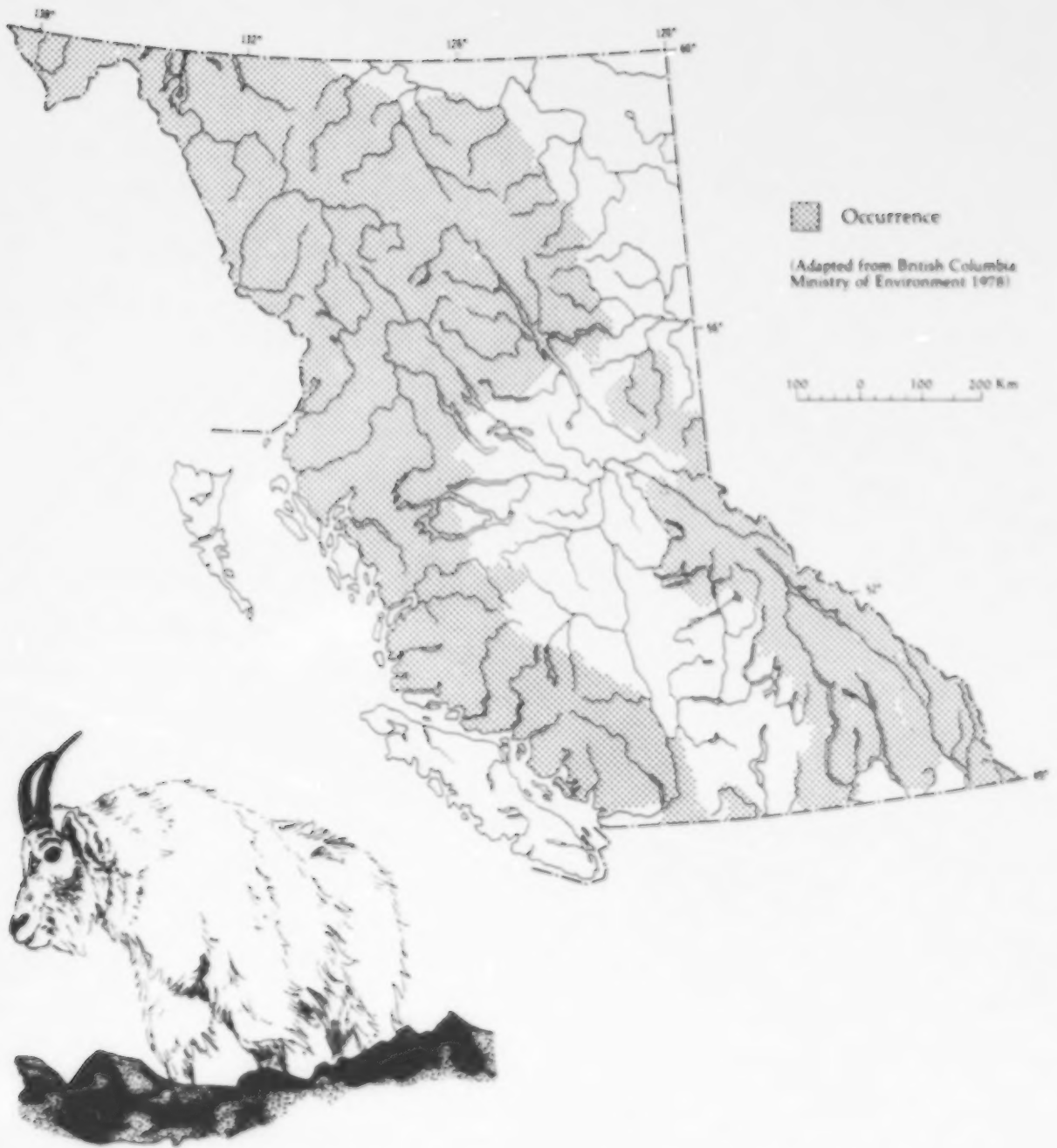


FIGURE 9. Example of a distribution map: mountain goat (Stevens and Loftis 1988, p. 145).

2.1.2 Habitat evaluation: structure of models

For each species and habitat class (or special element) combination, a table was compiled showing predicted overall use of the habitat and, if significant, season of use. Use was measured as relative abundance, based on literature and professional expertise and experience. Two scales of relative abundance were used, one for birds that could be tied to actual numbers of birds, and one for the other three vertebrate classes that was more subjective (see Figure 10). Models were only built for the habitats that had relative abundances better than scarce, unless the lower relative abundances were the best available in the ecoprovince. In other words, if the species was never more common than scarce or rare, then those habitats were modelled. It was generally thought that efforts to manage habitat for species would occur in habitats with better suitability.

HABITAT	SEASON OF USE	RELATIVE ABUNDANCE
Douglas-fir - ponderosa pine	yearlong	common
Douglas-fir - lodgepole pine	winter	common
Engelmann spruce - subalpine fir	yearlong	common
dry forested		
talus/rock	yearlong	abundant
dry alpine	yearlong	common
alpine meadow/subalpine meadow	summer	common
cliffs	yearlong	abundant

FIGURE 10. Sample of a table showing relative abundance, by season and habitat, for a species: mountain goat (Ritcey *et al.* 1988, p. 215.)

The species-habitat models used in the Wildlife Habitat Handbook are not complex. The habitat classes are fairly broad, so that within a biogeoclimatic subzone, one might find only three forested habitats: dry, mesic, and wet. For some wildlife species whose habitat relationships are well known (e.g., mule deer, moose), this is simplistic. For little-known species (e.g., long-tailed vole), this is complex. These models were compiled by a group of species experts, based on their professional expertise combined with known information from the literature (compiled as species notes or narratives) on habitat requirements for various life functions such as feeding or reproduction. The habitat classification is based on a province-wide system developed for the regional habitat plans.² Habitat classes are directly linked to ecosystem (site) associations of the B.C. Forest Service; they can be loosely interpreted from forest cover data in combination with biogeoclimatic subzones. The habitat evaluation process provides a predictive value of habitat suitability, by species, for each significant difference in seasonal and life requisite, for each subdivision of the habitat classification (e.g., habitat class successional/canopy closure unit, special element) (see Figure 11). A four-part coefficient scale was used, which is directly linked to the ungulate capability classification system that has been used in British Columbia for many years (Demarchi *et al.* 1983). These classes are high, moderate, low, and nil (see Table 1 for definitions). We tried to describe each class relative to the others; for example,

² Harcombe, A.P. and E.C. Lea. 1990. Wildlife habitats of British Columbia. B.C. Min. Environ., Lands and Parks, Wildl. Branch, Victoria, B.C. Draft report.

moderate is only half as good as high, and therefore one would require twice as much of that class of land to support a comparable number of animals. We did this so that we could translate suitability values into densities and "add up" different land units of different values. This was copied directly from Hoover and Willis (1984) in their Colorado publication. The MOELP wildlife program is currently using this same rating scale for some of its broader capability mapping projects; it seems to reflect relative differences reasonably well.

HABITAT Douglas-fir - ponderosa pine																				
SEASON OF USE summer																				
LIFE REQUISITES	G F R O A R S B S/	SHRUB/ SEEDLING			POLE- SAPLING			YOUNG			MATURE			OLD GROWTH			SPECIAL ELEMENTS			
		S	M	D	S	M	D	S	M	D	S	M	D	S	M	D	DM	SN	DEC	
FEEDING	1	m	1					1			1			1						
REPRODUCTION																				

FIGURE 11. Sample of a species-habitat relationship model: mountain goat (Ritcey *et al.* 1988, p. 215).

TABLE 1. Suitability coefficients and their definitions

Coefficient	Definition
HIGH	Provides for life requisites (feeding, reproduction, or designated special needs) and supports a relatively high population density (as implied by probability of occurrence of greater than 50%); can support positive recruitment (and increasing population or a stable population with dispersal)
MODERATE	Provide for life requisites; supports medium population density (as implied by probability of occurrence of 26-50%); can support a stable population, with no dispersal excess
LOW	Provides for life requisites; supports relatively low population density; supports viable population only with immigration or inhabited primarily by colonizing individuals
NIL	Designated that the habitat component is judged to be a little or no value to the species because it does not meet a species life requisites. The species is not expected to occur in the habitat

Converting habitat suitability indices to population density numbers is very difficult. The simple approach taken for the first attempts was to use home range size as a measure of habitat required, assuming literature values related to optimum or high-value habitat (Figure 12). No overlap of home ranges was considered. Therefore, if each pair of animals had a home range of 20 ha, and the planning area contained 100 ha of high-value reproductive and feeding habitat, the result was a prediction of five pairs (based on habitat suitability). This is perhaps the weakest part of the database, most subject to change. Initial values have been estimated for all the species; by printing them in a separate appendix, upgrading can be done (or the look-up tables can be modified) without changing the actual habitat evaluation. Some other assumptions must be made or somehow incorporated in the modeling. The first has to do with minimum habitat size before it should be counted; the second with

modeling. The first has to do with minimum habitat size before it should be counted; the second with habitats being evenly distributed in the watershed so that two necessary habitat components are close enough together to be used by the animal. Again, this assumption follows the U.S. method of assessment.

2.1.2 Habitat database

The habitat database may be derived from various sources. However, efficiency dictates that this habitat information be available for use on a GIS, with a set of digitized polygon map units and an associated set of attributes. A reference database (or look-up table or crosswalk table) is created that identifies the habitat units for all perceived combinations of mapped attributes. For the pilot watershed, these attributes were primarily dominant tree species and biogeoclimatic subzone. If the tree species and subzone in the GIS database match the corresponding fields in the reference database, then the GIS field (e.g., HABITAT_CLASS) is replaced with the habitat unit in the reference database. At the end of the update, all records with blank habitat units can be displayed and the operator can determine whether data are missing or incorrect, or whether a new combination should be added to the reference database. All the calculations will be performed with dBASE IV using UPDATE QUERIES. These updates allow the fields in one database file to be replaced with the fields in a reference database that matches selected criteria in another database. The main problem is the incompleteness of digitized databases containing appropriate habitat information. Crosswalking habitat units to forest cover attributes is not too bad with forested units, but becomes much weaker for non-forested polygons. It is hoped that MOELP's ongoing initiative to combine digital terrain data with satellite imagery to create baseline thematic maps of present cover and present land use will greatly increase our ability to make accurate assignments of polygons to particular habitat units.

At present, we have not developed a component for allowing successional growth to be automatically included as time passes, nor is there an automatic means of adjusting the habitat database under different land use scenarios. This still needs to be investigated. As better digital databases become available, the "accuracy" of habitat unit assignment to a look-up table should improve.

2.1.4 Habitat evaluation: analysis framework

As with the assessment of habitat, a reference database of habitat qualities contains the evaluation ratings for all life requisites of all the wildlife species. Fields will be created in the GIS database to contain the result of the queries. A field will be created for each species and the appropriate update will be applied. dBASE IV also can be used to summarize the data. Totals of all habitat qualities across all polygons on the mapsheet could be performed for each species, or for each species and life-requisite combination, using the TOTAL command. Standard summary tables and printouts will be produced, using REPORT FORM. The power of dBASE IV will supposedly obviate the need for any programming to calculate habitat suitabilities, as was initially proposed. For each species, there should be a target population level, an acceptable population, and a critical population level. This latter could be the minimum population figures provided in the species density matrices (see Figure 12). It has been suggested that the target population be 10 times the minimum or critical population, and the acceptable level be 5 times the critical level. These could be translated into acceptability codes, such as:

- Very good - more than 2 times the target population
- Good - the target population
- Acceptable - more than 5 times the critical population
- Critical - within 5 times the critical population.

This would allow for some "common" level of evaluation and understanding for the biologist. Histograms of the numbers of species in each acceptability category would be an informative display, and would be easy to compare among scenarios. These levels could also appear as background on graphs showing population numbers over time, for different scenarios (see Figure 13).

The models are the best we can now do without incurring extensive delays to accumulate new knowledge. They are aimed at indicating potential direction in population trend with changing habitats. When suitability values are plotted over time, as habitat changes, it is possible to get an indication of impact direction for each species (i.e., population increasing, population decreasing, population relatively stable).

White-tailed Jackrabbit

MINIMUM POPULATION 25		
MINIMUM HABITAT AREA (HECTARES) 2500		
AREA (ha) REQUIRED FOR	PER INDIVIDUAL	
	SUMMER	WINTER
FEEDING	100	
REPRODUCTION	50	
TOTAL	100	

Yellow-pine Chipmunk

MINIMUM POPULATION 50		
MINIMUM HABITAT AREA (HECTARES) 50		
AREA (ha) REQUIRED FOR	PER INDIVIDUAL	
	SUMMER	WINTER
FEEDING	1	
REPRODUCTION	1	
TOTAL	1	

FIGURE 12. Samples of species density–optimum habitat area values (Ritcey *et al.* 1988, p. 237).

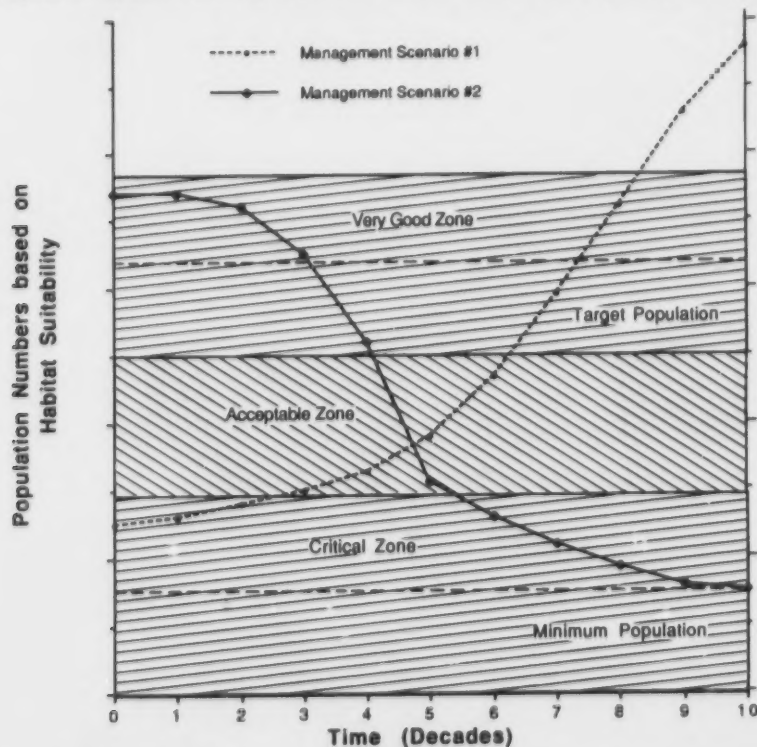


FIGURE 13. Sample output, in projected population numbers, for two alternative management scenarios.

2.2 Utilization of the System

Because the tool is a software tool, it should be easy to put into use in the field and the regions. It is anticipated that, initially at least, the existing habitat inventory for a selected area will be compiled by foresters, since they have access to the digitized map base of forest cover. The actual species selection will be the role of the biologist. Various scenarios should be jointly prepared, based in part on watershed development plans and partly on proposed wildlife objectives for an area. For the pilot project, two or three scenarios will be evaluated. The use of the system will be shown in two ways: by on-site extension and demonstration, using the pilot watershed data, and by user manual. It is planned that the tool will include various help screens, so that this "manual" is included with all software.

To date, it has proved very difficult to visualize fully the final tool and its needed output formats because it has been difficult to ask the biologists the right questions without some real "hands-on" material. There is a need to work closely with these regional biologists, since their help will be needed in setting up good methods of choosing species and generating habitat scenarios. They will set habitat objectives and guidelines from the output data. We envision that much regional interaction will be necessary before a final tool is operational.

2.3 Questions

There are a number of important questions still in need of resolution. Most have to do with using the tool in a manner that is connected to approved objectives and how the various outputs can be used to help in making good management decisions without becoming inflexible. There is the need to improve the "habitat growing" portion of the tool; it would be best if successional change could be included in the model, and if there was an easier way to incorporate changes derived from management scenarios. There are the important questions of selecting species, especially in light of the experiences of the National Forest managers (Landres *et al.* 1988). There is also the growing need to pay more attention to impacts of habitat fragmentation and genetic viability.

LITERATURE CITED

- Bailey, R.G. 1980. Descriptions of the ecoregions of the United States. USDA, Washington, D.C. Misc. Pub. No. 1391. 77 p.
- B.C. Wildlife Branch. 1991. Managing wildlife to 2001: a discussion paper. B.C. Min. Environ., Lands and Parks, Victoria, B.C.
- Brown, E.R. (technical editor). 1985. Management of wildlife and fish habitats in forests of western Oregon and Washington. USDA For. Serv., Portland, Ore.
- Cannings, R.A. and A.P. Harcombe (editors). 1990. The vertebrates of British Columbia: scientific and English names. Royal British Columbia Museum, Victoria, B.C. Heritage Record No. 20, Wildl. Rep. No. R24.
- Demarchi, D.A., B. Fuhr, B. A. Pendergast, and A.C. Stewart. 1983. Wildlife capability classification for British Columbia: an ecological (biophysical) approach for ungulates. B.C. Min. Environ. Surveys and Resource Mapping Br., Wildl. Evaluation Unit, Victoria, B.C. 57 p.
- Demarchi, D.A., R.D. Marsh, A.P. Harcombe, and E.C. Lea. 1990. *In* Birds of British Columbia. Vol. 1. R.W. Campbell, N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser, and M.C.E. McNall (editors). Royal British Columbia Museum, Victoria, B.C. pp 55-144.
- Harcombe, A.P. (technical editor). 1988. Wildlife habitat handbook for the Southern Interior ecoprovince. Vol. 1-8. B.C. Min. Environ. and B.C. Min. For., Victoria, B.C.
- Harcombe, A.P., C.J. Clement, and F. Russell. 1992. Wildlife habitats. *In* Wildlife habitat handbook for the Southern Interior ecoprovince. A.P. Harcombe (technical editor). Vol. 9. B.C. Min. Environ. and B.C. Min. For., Victoria, B.C.
- Hoover, R.L. and D.L. Willis (editors). 1984. Managing forested lands for wildlife. Col. Division of Wildl. in cooperation with USDA For. Serv. Rocky Mount. Region, Denver, Col.
- Landres, P.B., J. Verner, and J.W. Thomas. 1988. Ecological uses of vertebrate indicator species: a critique. *Conserv. Biol.* 2:318-328.
- Ritcey, R., D. Low, A. Harestad, R.W. Campbell and A.P. Harcombe. 1988. Species-habitat relationship models for mammals. *In* Wildlife handbook for Southern Interior ecoprovince. A.P. Harcombe (technical editor). Vol. 5. B.C. Min. Environ. and B.C. Min. For., Victoria, B.C. 245 p.
- Stevens, V. and S. Lofts. 1988. Species notes for mammals. *In* Wildlife handbook for the Southern Interior ecoprovince. A.P. Harcombe (technical editor). Vol. 1. B.C. Min. Environ. and B.C. Min. For., Victoria, B.C. 174 p.
- Thomas, J.W. (technical editor). 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. USDA For. Serv., Portland, Ore. Agric. Handb. No. 553.

4



Assessing and Planning the Spatial and Temporal Features of Black-tailed Deer Habitat

Marvin Eng
B.C. Ministry of Environment,
Lands and Parks
Wildlife Branch
780 Blanshard Street
Victoria, B.C.
V8V 1X5

Scott McNay
B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7

Doug Janz
B.C. Ministry of Environment,
Lands and Parks
Fish and Wildlife Branch
2569 Kenworth Road
Nanaimo, B.C.
V9T 4P7

Laurie Kremsater
University of British Columbia
Faculty of Forestry
270-2357 Main Mall
Vancouver, B.C.
V6T 1W5

Ian MacDougall
B.C. Ministry of Environment,
Lands and Parks
Fish and Wildlife Branch
2569 Kenworth Road
Nanaimo, B.C.
V9T 4P7

Rick Page
B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C.
V8W 3E7

SUMMARY

The lack of integration between the activities of forest and wildlife managers has often led to conflict. In 1980, a cooperative research program between the B.C. Ministries of Environment and Forests was begun to help resolve one such conflict: the fate of valuable old-growth timber set aside as winter habitat for black-tailed deer on the south coast of British Columbia. Previous approaches to resolving this conflict have included the "referral system" and the "interdisciplinary team approach." These methods could be described as reactive and proactive, respectively. Both these methods are labor-intensive and based on manual interpretation of paper maps.

We describe an alternative approach called the Habitat Assessment and Planning (HAP) tool. The HAP tool is a series of micro-computer based models that allow wildlife and forest managers to incorporate the spatial and temporal aspects of wildlife habitat while developing habitat plans and operational forestry plans. The HAP tool consists of three models: 1) regional priorities, 2) watershed assessment, and 3) management options. These models are designed to be used in an iterative fashion to increase the benefits of habitat management. The structure and operation of the tool is discussed.

An example application of the regional priorities model and the watershed assessment model is discussed. The results of the example application of the prototype regional priorities model indicated several improvements that could be made to the model. Current development efforts for the HAP tool are focused on the watershed assessment model. We describe how a geographic information system is used to model winter habitat quality for black-tailed deer. We also show how the resulting habitat quality maps can assist managers in making decisions about habitat management needs and the impact of forest harvesting scenarios on deer habitat quality.

Plans for further development and eventual operational implementation of the HAP tool are discussed. We present the opportunities and constraints for implementation and some suggestions for overcoming constraints.

ACKNOWLEDGMENTS

The need to recognize spatial and temporal factors when assessing wildlife habitat has been implicitly recognized for years. A handful of biologists and managers in the U.S. Pacific Northwest and in British Columbia have acted as catalysts in making that principle not only explicit but a priority research topic for integrated management of timber and wildlife. We thank Don Eastman, Rick Ellis, Rick Holthausen, Bruce Marcot, Brian Nyberg, and Hal Salwasser for their support for the Habitat Assessment and Planning project and for their continued review of our progress. Habitat Assessment and Planning is funded by the Integrated Wildlife — Intensive Forestry Research program, a cooperatively funded and administered program of the B.C. Ministry of Forests, the B.C. Ministry of Environment, Lands and Parks, and the University of British Columbia.

TABLE OF CONTENTS

SUMMARY	82
ACKNOWLEDGMENTS	83
1 PROBLEM REFERENCE	86
1.1 Planning for Integrated Management of Timber and Deer	86
1.2 Previous Approaches to Planning	86
1.3 Alternatives to Current Methods	87
2 CASE EXAMPLE: THE HABITAT ASSESSMENT AND PLANNING (HAP) TOOL	89
2.1 Introduction	89
2.2 User Profile	89
2.3 Task Profile	90
2.4 HAP Development Concepts	91
2.4.1 The planning unit	91
2.4.2 Scale and resolution	91
2.4.3 Uncertainty and Risk	91
2.4.4 Optimization versus decision aid	92
2.4.5 Reductionism versus holism and Occam's razor	92
2.5 General Description of components	93
2.5.1 Regional priorities model	94
2.5.2 Watershed assessment model	94
2.5.3 Management options model	94
2.6 Example Application of HAP	95
2.6.1 Regional priorities model	95
2.6.2 Watershed assessment model	97
3 TOOL DEVELOPMENT AND IMPLEMENTATION	107
LITERATURE CITED	110

FIGURES

1 Conceptual framework for the habitat assessment and planning tool	93
2 Regional priorities model structure	96
3 Level of disagreement among users who applied the regional priorities model to two small areas on Vancouver Island	97
4 Black-tailed deer winter habitat suitability model structure	98
5 Forage quality ratings for the Coastal Western Hemlock variants that occur in the assessment area	100
6 Cover quality ratings for the Coastal Western Hemlock variants that occur in the assessment area	101

7	Ratings for distance from food and cover during mild and severe weather conditions	102
8	Ratings for combined aspect and elevation categories	102
9	Current (year:1990) winter habitat suitability for black-tailed deer	104
10	Projected (year:2020) winter habitat suitability for black-tailed deer	105
11	Summary of black-tailed deer winter habitat in the assessment area	106

1 PROBLEM REFERENCE

1.1 Planning for Integrated Management of Timber and Deer

Habitat management is commonly used to achieve wildlife population objectives. In British Columbia (B.C.) wildlife managers do not have direct control over the habitat manipulations that result from extensive forestry programs. Foresters, who do have the control, are often unaware of the effect of their activities on wildlife habitat. The resulting lack of integration of the two management activities (forest and wildlife management) has led to conflicts. The specific impetus for this project is a long-standing indecision over the fate of old-growth stands set aside as winter habitat for black-tailed deer (*Odocoileus hemionus columbianus*).

The issue has important economic and social implications. Currently on Vancouver Island, black-tailed deer winter ranges represent approximately 50 000 ha of old-growth timber that have been deferred from logging for up to 10 years. The estimated net value of this timber is more than \$50 million (B.C. Ministry of Environment and Ministry of Forests 1983). Black-tailed deer are worth in excess of \$5.2 million per year in total revenue from hunting (Reid 1985a, b) and probably the same amount in non-consumptive use (Reid *et al.* 1985). Within the coastal region of British Columbia, black-tailed deer receive 93% of the total hunter days allocated to all big game species (Reid 1985a, b). In addition, there is a substantial political lobby that advocates the incorporation of non-timber values into forestry plans.

More than 35 000 ha of coastal B.C. forests are harvested annually and the impact of forest management on deer habitat is both extensive and rapid. What was once predominantly old-growth forest is now a mosaic of even-aged stands of young conifers interspersed with patches of old growth. While site-specific habitat management techniques (Nyberg *et al.* 1989) can help managers resolve some conflicts, they are not sufficient. Managers also need to assess the implications of their actions in the context of regional and watershed-scale planning. Here, we address the issue of planning forestry and deer habitat management over areas larger than a "site" (stands of 10^2 ha).

Shifting focus from site-specific habitat management techniques to planning for entire watersheds (10^4 ha) is difficult because each habitat problem must be put in the context of the larger land base and the life-long habitat needs of the animals. Deer must move to obtain resources. They require different things at different times and in different places. For example, the proximity of spring forage habitat will influence the ultimate value of management to improve winter habitat quality. The spatial and temporal integrity of the planning exercise becomes essential.

Yet another problem arises because timber development and habitat management occur at very different "operational" planning horizons. Foresters usually allocate harvesting through a 5-year development plan process, base their activities on individual forest stands, and assess value as the volume of merchantable wood per unit of land. Deer habitat managers should plan over longer time frames (often 20 years or more), base their activities on watersheds, and assess value as supportable harvest levels. The difference in planning horizons is, once again, largely because deer must move to secure resources and trees do not. Because trees are stationary, inventory and area-based planning for the forestry values is both easier and less significant than it is for the wildlife values. How then does one integrate planning for two values when one is specific in time and space and the other is not?

We use black-tailed deer and coastal forestry as our example of problems in integrated planning. However, the issues raised extend beyond these to most geographic areas (not just B.C.) and to many other forest-dwelling animals.

1.2 Previous Approaches to Planning

Two planning approaches have been used to attempt integrated management of forests and wildlife in B.C.: the "referral system" and the "interdisciplinary team" approach.

The "referral system" is used predominantly. Responsibility for planning and conduct of logging and silviculture is delegated, in most coastal areas, to private firms with area-based cutting rights. Government

agencies, led by the British Columbia Forest Service (BCFS) approve and monitor company programs. Companies have no responsibility for wildlife. Company plans are sent ("referred") to the Ministry of Environment, Lands and Parks (MOELP) and the federal Department of Fisheries and Oceans for comment on wildlife and fishery impacts. The referral system discourages incorporation of deer habitat concerns early in the planning process and puts MOELP in a reactive position. The process stipulates short-term planning (usually a 5-year planning horizon) and forces wildlife managers to focus on a stand-by-stand scale; both are inappropriate for effective wildlife habitat planning. The fact that several different tenures and forest companies can occur within the same watershed compounds this problem. As a result, short-term logging development is favored over long-term timber and wildlife habitat planning.

The "interdisciplinary team" approach is occasionally used for watersheds with high timber value and strong conflicts with other resource values. Under this system, a designated lead agency brings together a group of experts to formulate a set of joint resource objectives and develop an integrated resource plan. This approach is more conducive to development of a long-term integrated plan but it requires many specialists and it is very time consuming. These special requirements usually preclude use of the interdisciplinary team approach.

The following example illustrates the problems in planning for integrated management of deer and timber in coastal B.C. This example concerns the interdisciplinary team approach as applied to the Artlish River watershed on northern Vancouver Island. The goal was to develop a "Local Resource Use Plan" to guide multiple-use development on the 15000-ha watershed. Involved were three licensees, two forms of tenure within two forest districts, and the MOELP.

A biophysical mapping exercise was the basis for determining capability of the land to support deer and elk. Physiographic and biogeoclimatic units (*sensu* Klimka *et al.* 1984) were used to interpret and map ungulate winter habitats and to delineate potential for high-quality spring and summer forage production sites. Forest cover and logging operability maps were compared (manual overlay method) with wildlife capability to identify conflict areas. The map comparison was also used to assess trade-offs and to plan long-term logging development given the constraints of tenure type, annual cut requirements, and wildlife habitat values. A 20-year logging plan was developed. It incorporated considerations for deferral of winter habitats, replacement of old-growth stands with managed young growth, and the spatial and temporal patterns of forage and cover on the seasonal ranges.

There were three major difficulties in the Artlish exercise. First, staff and time were too limited. The overall procedure took several years of dedicated, but often interrupted work (primarily compiling and drafting maps).

Second, it was very difficult to schedule forest management mentally over a 20-year time frame and simultaneously evaluate impact on habitat values. That difficulty arose because habitat values are partially dependent upon the spatial arrangement of specific habitat features and that arrangement is unique at each point in space and it changes with each forest harvesting operation.

Third, records of the decisions made (paper files and maps) were inadequate for purposes of recall and updating. Frequent staff changes made this situation even worse. Other problems will result from an inability to monitor the development in the Artlish and to evaluate the decisions that were made. Few records are available of changes made to the plan, including changes to forest development plans and possible changes in tenure types.

1.3 Alternatives to Current Methods

Wildlife ecologists have understood and accepted the core concept of the Habitat Assessment and Planning (HAP) approach for over 50 years; that is, the interspersal of life requisites is critical in determining the value of an area as habitat (Leopold 1933).

Interspersal reflects the distance an animal must move between any two life requisites. For example, if good winter and summer habitat are available in the same area, deer can be resident year-round. Seasonal migration, on the other hand, allows seasonal habitats to be separated in space and still be efficiently used. How deer find, and learn to use, more dispersed seasonal ranges or alter their basic

movement tactics in the face of changes resulting from forestry must constrain how seasonal habitats are managed (McNay *et al.* 1988).

Within a seasonal home range, the interspersed daily life requisites is important. In particular, the energetic costs of movement can be substantial during winter, and hence food and cover must be close together. Many stands (habitats) provide either food or cover but not both. Therefore, the stands must be suitably arranged to provide effective seasonal habitat.

Attempts have been made to incorporate habitat interspersed into wildlife habitat models and planning using "interspersed indices" of varying complexity (Heinen and Cross 1983). However, these indices do not adequately represent wildlife habitat because they "add up" interspersed over large areas and do not represent the relationship among individual habitat polygons (stands). Adequate representation of spatial interspersed is only possible by processing habitat data while retaining its spatial integrity. This was not feasible until the advent of computerized map analysis (geographic information systems [GIS]). Useable micro-computer based GIS software has only recently become available, thus the use of GIS in natural resource management is still in its infancy (Coughlan and Olliff 1988). Some results, however, show the potential use of GIS for analyzing spatial interspersed of habitats (Lyon *et al.* 1987).

GIS offers the potential to increase awareness and knowledge of the spatial and temporal interactions between deer and forest management activities. Such increase in awareness would help to ensure that deer habitat requirements entered the referral process early (Nyberg *et al.* 1989). As well, the rapid pace and large extent of forest management activities will require automated analytical tools before long-term planning can happen on a routine basis. GIS would:

1. enable the assessment of watershed-wide impacts resulting from site-specific management prescriptions;
2. help reduce the need for excessive staff inputs;
3. handle map construction tasks quickly; and
4. maintain pictorial and/or textual records of decisions for use at a later time.

Projecting and evaluating habitat changes through time is repetitive and time consuming. The large volume of data makes the chore impossible for humans but suited for computers. Nevertheless, there are hardware and software limitations. The tool should function on currently available computer technology (or at least on technology that will be widely available in the near future). The aim to accommodate hardware and software limitations must be balanced with the risk of constructing a tool that is too simple and will suffer from lack of credibility.

Regardless of which type of analytical tool is developed, it might not be acceptable to all users (forest and wildlife managers as well as planners). To counter that tendency, as many users as possible should be involved with the construction of such a tool.

Lastly, there is the risk associated with accepting the status quo and not proceeding with the development of any new analytical tool. In that case, integrated management would likely never be well planned, largely due to incompatible planning horizons for two vastly different values: timber and deer. Also, our understanding of planning integrated management would be limited without such an analytical tool to guide research studies of animal responses to long-term, large-scale habitat changes.

2 CASE EXAMPLE: THE HABITAT ASSESSMENT AND PLANNING (HAP) TOOL

2.1 Introduction

In this section, we describe the application of a planning tool being developed by the B.C. Ministry of Environment, Lands and Parks, and Ministry of Forests. The goal of the Habitat Assessment and Planning (HAP) project is to develop a planning aid that will translate research knowledge about the habitat relationships of black-tailed deer on Vancouver Island and the south coast of B.C. into effective tools for wildlife and forestry managers. The HAP tool will be a series of micro-computer based models that will allow planners to incorporate the spatial and temporal aspects of habitat while developing harvest schedules, habitat plans, and operational forestry plans. The ideal HAP tool would allow planners to:

1. assess the quality of deer habitat (watershed-wide) and the impacts of proposed forestry plans and activities on that habitat;
2. provide information to recommend changes in plans that will minimize negative impacts or maximize the benefit of forestry on deer habitat;
3. identify the risks of pursuing uncertain management actions and, where possible, identify the data required to reduce the uncertainty;
4. assess priorities for, and the cost-effectiveness of, habitat management (enhancement) projects; and
5. provide documentation that can be used to evaluate the rationale for decisions that affect deer habitat.

The HAP tool will be a complete framework for integrating wildlife habitat planning concerns into forest planning methodology in B.C. Initially, HAP will be applicable to black-tailed deer on Vancouver Island and the south coast of B.C. This tool, however, should be viewed as a prototype of a more generally applicable tool that could be used throughout the province (or the world) for any wildlife species. An elk habitat quality model that will be incorporated into the HAP framework is currently being developed and validated by a separate research project¹.

The approach will be to develop a complete framework for the "ideal" HAP tool. Component parts of the framework will then be developed to the level of detail that is possible, given technological and administrative constraints (Section 3). The HAP tool delivered by this project will be functionally complete. It will, however, make use of "expert opinion" where policies or data are lacking, and "manual methods" where computer models are lacking. The tool will be developed with an "open-ended" architecture, allowing incorporation of new data or models.

The HAP tool will not be constrained by current methods of planning, particularly at the strategic level, within the B.C. government. Forest planning methods are in a state of flux as new planning procedures are being developed (e.g., Dellert and D.H. Williams & Associates Ltd. 1989). As well, growing public concern over integrated resource management may change forest planning. The HAP tool must be able to fit into the strategic forest planning system that eventually results, but development of the HAP tool should not be constrained by current suppositions about that planning system.

2.2 User Profile

The HAP tool will help three groups of professionals involved in forest planning:

1. Regional Habitat Protection Biologists and Technicians within the MOELP who have the primary objective of minimizing negative impacts of forestry activities on wildlife habitat;
2. Foresters in BCFS at both regional and district offices who have the primary objective of ensuring that Ministry of Forests policy is met by forestry operators; and

¹ Brunt, K. 1989. Application of a geographic information system (GIS) to test models of Vancouver Island Roosevelt Elk habitat suitability. Unpublished M.Sc. thesis proposal. Univ. Victoria, Dep. Biology, Victoria, B.C. 19 p.

3. Divisional forest planners in the timber industry who have the primary objective of minimizing the cost of timber harvesting.

As well as having different objectives, these groups have very different backgrounds, job experience, computer experience, facilities, and resources.

The user groups with the greatest immediate need for the HAP tool are the Habitat Protection Biologists and Technicians, because the referral system is the most commonly used planning method in B.C. (Section 1.2). As well, these users are the most knowledgeable about habitat requirements and forestry impacts on habitat. Therefore, these groups will be most able to identify needs for improvement in the HAP tool. For these reasons, HAP will be initially designed for these users. During development, consideration will be given to the needs and capabilities of the other potential user groups.

2.3 Task Profile

The HAP tool will support a variety of tasks performed by all three user groups. These tasks include the development of, or response to, 5- and 20-year plans for Timber Supply Areas (TSA's) and Tree Farm Licences (TFL's) and the development of Local Resource Use Plans and small business plans. We expect forest planning to progress eventually to the point where rotation-age plans are created using a planning method that is spatially explicit. Initial development of the HAP tool will concentrate on aiding MOELP staff in responding to 5-year "operational" plans submitted by forestry companies or the BCFS. This task represents a major portion of the work load for the "prototype" user groups (Habitat Protection Biologists and Technicians). The task is complex and requires an understanding of species' habitat requirements, forest successional patterns, and local conditions. Recommendations that frequently result from such a task include:

- long-term deferral of logging of old-growth stands that represent high-quality winter range for black-tailed deer;
- short-term deferral of old-growth stands that represent future foraging areas and potential visual cover;
- changes in cutblock location, size and shape to minimize impacts on sensitive habitats;
- changes in the harvesting mosaic to obtain favorable "green-up" patterns;
- changes in scheduling of spacing and thinning operations to enhance desired cover or forage attributes; and
- changes to road layouts or logging methods to minimize harassment of wildlife.

Five-year plans are normally submitted early in the calendar year and Habitat Protection staff are expected to respond to them before the end of March. Technicians may have up to 10 plans to respond to at any one time. The response to each plan can take from 20 to 120 hours to prepare, depending on the complexity of the plan, the size of the planning area, and the sensitivity of wildlife issues involved.

Habitat Protection Technicians' satisfaction with the current method of processing referrals is low because:

- much of the task involves menial and repetitive comparison of new and old plans to detect changes from year to year, and the processing and filing of responses to plans;
- there is a heavy reliance on site-specific knowledge but very little time is available to obtain site-specific information;
- the extreme complexity of the spatial and temporal interactions of habitat quality are very difficult to assess manually, resulting in possible errors and overly conservative recommendations; and
- the task is so time consuming that adequate time to respond to other kinds of referrals (municipal, industrial, etc.) is not available.

Use of the HAP tool will help alleviate these problems by:

- automating many of the menial aspects;
- identifying areas where site-specific knowledge is critical;
- reducing the apparent spatial and temporal complexity by modeling those aspects of habitat quality; and
- reducing the total time required to prepare a response.

2.4 HAP Development Concepts

2.4.1 The planning unit

The HAP tool must be applied within some circumscribed planning unit. Regional forestry plans are prepared for entire TFL's or TSA's (10^5 – 10^6 ha). This is too large an area to be an effective planning unit for wildlife habitat because of variability in conditions throughout the area. As well, TFL boundaries are based on administrative considerations and habitat planning units should be based on environmental considerations. Operational forestry plans, on the other hand, are designed on a stand-by-stand basis and hence are too small to incorporate the habitat requirements of even a single large animal. Ideally, the habitat planning unit should relate to population characteristics. For deer the best planning unit is most likely to be the "watershed." Biological evidence for the planning unit definition is a subject of research on related projects (McNay *et al.* 1988; McNay and Morgan 1989). For black-tailed deer it is likely that an effective planning unit could be defined using some combination of watershed boundaries and snowpack zone boundaries (Nyberg and Janz 1990).

2.4.2 Scale and resolution

Time scale is dictated mainly by forest planning procedures. Operational forestry plans are developed for 5-year periods and significant changes in wildlife habitat probably cannot be detected over a shorter time than this. The modeling process would ideally include 5-year steps through a full rotation for the managed forest.

The level of detail of the data required to model deer habitat adequately is still unclear. Our current modeling efforts are based on current vegetation cover maps prepared using the ecosystematic association (and successional stage) classification at a scale of 1:20 000. Our elevation and aspect polygons are based on visual interpretation of 1:50 000 topographic maps. These sources appear to be adequate for modeling exercises. It is necessary to assess the impact of lower quality information (e.g., forest cover data compared to ecosystematic classification data) on the model output. Conversely, we will determine whether or not higher-quality information (e.g., digital terrain models compared to topographic maps) improve the model output.

These questions and many like them can only be answered through data analysis and model creation and validation. There will probably be more than one answer to many of the questions involving data resolution. Data requirements will vary with the specific nature of management questions and the geographical area of interest. For black-tailed deer we currently accept that 200 m elevation classes are sufficiently precise and that forest cover maps provide insufficient indication of understory forage production.

We may be able to infer understory from other relationships (such as among forest cover, soil type, aspect, and site history). A more promising approach is to use the habitat modeling to direct sampling effort at the relatively few stands where such data are needed. Rather than mapping the entire area for a precise attribute like forage, the information can be collected and entered only when needed. The elapsed time for an evaluation will obviously be lengthened, but this is an extremely efficient way of collecting data. We anticipate that the use of the HAP tool will frequently involve an iterative approach in which managers try to answer the questions with available data. The HAP tool will then generate a list of data requirements to answer the question adequately.

2.4.3 Uncertainty and risk

There is a strong tendency for computer-generated output to be treated with unacceptably high regard for precision (Hilborn 1987). Imprecise initial data sources can propagate and compound errors

dramatically, particularly with projections into the distant future. The usual solution is to attempt to increase the precision of the original data sources. However, this may be difficult and the increase in precision may still be insufficient to affect the quality of the model output. There are much better ways of dealing with uncertainty than accepting on faith that we have the "best" data possible.

One method of dealing with uncertainty is to conduct sensitivity analyses in which the scenario being assessed is intentionally biased in one direction and the effect on the management outcome is observed. For example, assume a 20% increase in rate of harvest knowing that 10% is the maximum permissible. How much difference will it make? What if an area that has experienced fairly mild winters suddenly encounters a series of winters with much greater snowfall. What impact would drier summers have on summer forage production?

Another method of dealing with uncertainty is to provide managers with the opportunity to practice adaptive management in their decision-making processes. Walters (1986: 159) advocates "adaptive management" because "many key management decisions are essentially gambles, no matter how nicely we may try to package the justification." Walters (1986: 257) suggests that we embrace, rather than ignore, the element of uncertainty in our decision making and use it to develop "actively adaptive policies." Actively adaptive or "dual control" policies seek to establish some optimum, or at least a reasonable, balance between learning and short-term performance.

2.4.4 Optimization versus decision aid

It is neither possible nor desirable to develop a HAP tool that would generate an "optimum" operational forestry plan for a planning unit. "Optimum" plans would require "rules" about biology and forestry that we cannot presently develop. As well, input from managers about the types of management actions will allow for adaptive management procedures (Walters 1986) to be developed and incorporated. By trying various scenarios in the real world and on the computer, documenting the assumptions and reasons behind the decision, and evaluating success or failure, we can gain knowledge most rapidly. This is expected to eventually improve forest management. The HAP tool should be viewed as providing information to managers for use in decision making rather than as providing a prescriptive tool.

2.4.5 Reductionism versus holism and Occam's razor

The biological system we are attempting to model is extremely complex. It might therefore be assumed that an adequate model must also be complex. This assumption generally leads to a "reductionistic" modeling philosophy. That is, "a whole can be understood completely if you understand its parts and the nature of their sum" (Hofstadter 1979). This approach has been successful for modeling simple systems not influenced by prior history, particularly in the field of physics. However, very little success has been attained in the field of "ecosystem" modeling. This lack of success stems not only from the extreme complexity of ecological systems but also because, for complex systems, "the whole is greater than the sum of its parts" (Hofstadter 1979). This alternate world view, known as holism, requires a "top down" approach to modeling in which the desired output is identified and the model includes only the necessary components of the system required to obtain that output.

The debate over the correctness or validity of the reductionist versus the holist world views will probably never be resolved because, to some extent, the question is flawed. That is, neither view is wrong or right (Hofstadter 1979). From a pragmatic point of view, however, modeling should be done on the basis of Occam's razor, that is, "it is vain to do with more what can be done with fewer" (Dunbar 1980). This approach is to build the simplest model that appears to "work." It is "holistic" in nature and requires an expert system model in which the expert specifies those aspects of the system believed to be most important for arriving at the desired model output.

The "Occam's razor" approach is advantageous for four reasons:

1. the resulting models are simple and can be clearly understood and "believed" by managers with expertise similar to that of the model developers;
2. model inputs are simple to obtain because they are frequently the opinions of experts;

3. models can be developed quickly and inexpensively; and
4. models live or die based on their management success ("the proof is in the pudding").

2.5 General Description of Components

The complete framework for the HAP tool currently has three parts:

1. a regional priorities model;
2. a watershed assessment model; and
3. a management options model.

Each model will have separate inputs and outputs. The outputs of each model will be linked as inputs to the other models so that the framework will be integrated and iterative (Figure 1). The regional priorities model will rank planning units (watersheds) in terms of the need for habitat management. For each high-priority planning unit, the watershed assessment model will evaluate the proposed forestry scenarios and specify the habitat management requirements. If no management requirements are identified, the process will return to the regional priorities model to obtain a new planning unit for assessment. If management requirements are identified, the management options model will be used to determine the cost/benefit ratio for the proposed management action. If a poor cost/benefit ratio results, the process will return to the regional priorities model to obtain a new planning unit for assessment.

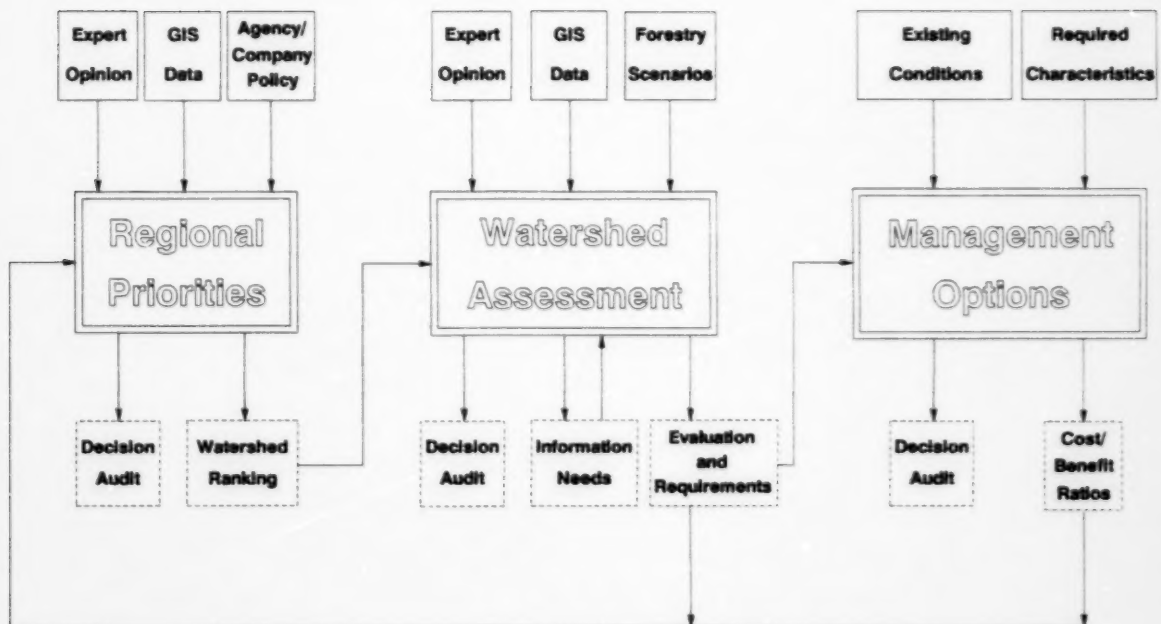


FIGURE 1. Conceptual framework for the habitat assessment and planning tool.

2.5.1 Regional priorities model

The regional priorities model answers questions about where, in a regional context, management efforts should be directed. An example question is: Where are deer management priorities so low that little or no effort is required for spacing/thinning to provide forage production, thermal cover, or winter range?² The model will be primarily an expert system that would require substantial knowledge about the geographical area and species of interest to operate effectively. The model would require user input to questions and it may obtain input from, or assist the user in providing input through, small-scale GIS data and government or industry policy information. Outputs would include a ranking of planning units (watersheds) in terms of the need for a detailed assessment of habitat quality and a decision audit that would record the reasons why the ranking occurred.

A prototype regional priorities model has been constructed (McNay *et al.* 1987; McNay and Page 1988). This model incorporates a decision hierarchy that attempts to mimic the thought processes of habitat biologists. The model attempts to find the limiting factor among three major questions:

1. Are deer a sensitive management issue from the point of view of predation, societal demand, etc.?
2. Is the topography potentially highly capable of supporting deer?
3. Is the current habitat quality comparable to the topographic capability?

These three questions are addressed by a series of specific sub-questions. The manager has the option of ignoring some of the specific factors in the model (such as predation) if he or she sees fit, but the basic logical structure of the decision-making process is fixed.

2.5.2 Watershed assessment model

The watershed assessment model is the core of the HAP tool. It should "help in resolving habitat management decisions over a watershed-sized area and through pre-determined time steps" (Harcombe and Baker 1987). The watershed assessment model will be GIS-based and will allow assessment of habitat quality of watersheds at a specific time. Temporal changes will be included by projecting the succession of forested land and repeating the watershed assessment at pre-determined time intervals. Model inputs will include large-scale GIS-based data on the present conditions of the watershed landscape (including descriptions of seasonal habitats and their interspersions), proposed operational forestry plans, and long-term forestry and wildlife objectives. Model outputs will be of three types:

1. **Decision Audit:** mechanisms that would record the results of the watershed assessment and the resulting management decisions so that future managers could evaluate those decisions. The decision audit mechanism would also assist in the day-to-day duties of the Habitat Protection staff (i.e., processing and filing of plan referrals).
2. **Information Needs:** an identification of locations (stands) in the watershed where the available data are not sufficient to allow a reliable assessment of the present or future habitat conditions.
3. **Evaluation and Requirements:** map-based, graphic, and tabular reports on the changes in habitat quality within the watershed through time, that would help managers assess the impact of proposed forestry plans and make recommendations to minimize the negative impacts. Additionally, there would be an identification of locations (stands) in the watershed where small changes in stand characteristics would result in large changes in habitat quality.

2.5.3 Management options model

The management options model will determine the most appropriate methods of achieving the habitat requirements identified by the watershed assessment model. Model inputs will be the required

² MacDougall, J. 1987. Phase II - problem analysis for second growth habitat: an overview for HAP (Habitat Analysis Procedure). B.C. Min. Environ. Unpubl. Memo. 5 p.

habitats and the existing habitat conditions. Model outputs would be cost/benefit ratios of site-specific habitat management actions. If it is determined that poor cost/benefit ratios result for all management options, then the regional priorities model would be re-applied to select a new watershed for evaluation.

Application of the management options model will involve an evaluation of the efficiency of different habitat management options rather than trade-offs between timber values and deer habitat values. Not all possible options can be evaluated. For many, we lack both information on likely costs and, in most cases, information on likely benefits to wildlife. A potential surrogate is to define break-even points. A hypothetical example would be: spring forage plantings must cost less than \$233/ha and benefit 51 deer. More likely, the model outputs would be relative benefits; for example, a specified amount of money will benefit more deer if Option A is applied in Area 1 than if Option B is applied in Area 2.

It is difficult to model "optimal" options because of the large number of interactions between site-specific needs and seasons. It may be that a lack of winter range in Area 1 can be alleviated by provision of better summer range in Area 2, so that migrators arrive in better condition. The number of such possible interactions exceeds current computing capabilities, but is manageable within the human mind. Once the manager decides that a possible management intervention is worth considering, the power of GIS and the management options model can be used to evaluate the possible habitat benefits.

This model may be relatively weak in the version of HAP that will be delivered (Section 3). The utility of many habitat enhancement options will only be demonstrated after many years and trials. The focus of this model will be a demonstration of how to evaluate options, with less focus on definitive recommendations to managers. We do not know at this point if the knowledge exists to make this model work. An adaptive management scheme to continuously evaluate the utility of this model is clearly required.

2.6 Example Application of HAP

Although the HAP tool is far from being complete, we felt that it was important to apply the tool to "sample" areas and to evaluate the results to guide overall direction as we proceed with tool development. An initial attempt to evaluate the regional model was achieved by having one of the model builders and two managers not familiar with the model assess the deer habitat in two small areas on Vancouver Island. The watershed assessment model was evaluated by applying the model to the study area used to collect the data for model development. The results of the model application were "visually" evaluated by the model-building team and a group of resource managers familiar with the area.

2.6.1 Regional priorities model

An attempt was made to evaluate the regional priorities model developed by McNay *et al.* (1987). This model uses the Deciding Factor (Channelmark Corp., San Mateo, Cal.) as the expert system software shell. Users are asked to provide information sensitivity of the deer management issue by answering specific questions about predators, demand for deer, density of deer, accessibility, and winter severity patterns. The sensitivity of the management issue is then weighed against the capability of the area to provide habitat (based on questions about biophysical parameters) and the current quality of the habitat (based on questions about the managed state of the habitat). The result is a relative rating of priority of the need for habitat management.

In the structure of the model (Figure 2) the first two hypotheses — (1) deer are a sensitive management issue and (2) topography is capable of supporting deer — both provide positive weight to the main hypothesis (habitat quality should be a concern). If deer are a more important issue in one area than another, then it follows that deer habitat would be of more concern there as well. Conversely, the third supporting hypothesis — (3) quality is comparable to capability — provides negative weight to the main hypothesis. If deer habitat is already high quality, then habitat management will be marginally effective in increasing the habitat quality. Only when habitat quality is low relative to capability would habitat management achieve any significant benefits.

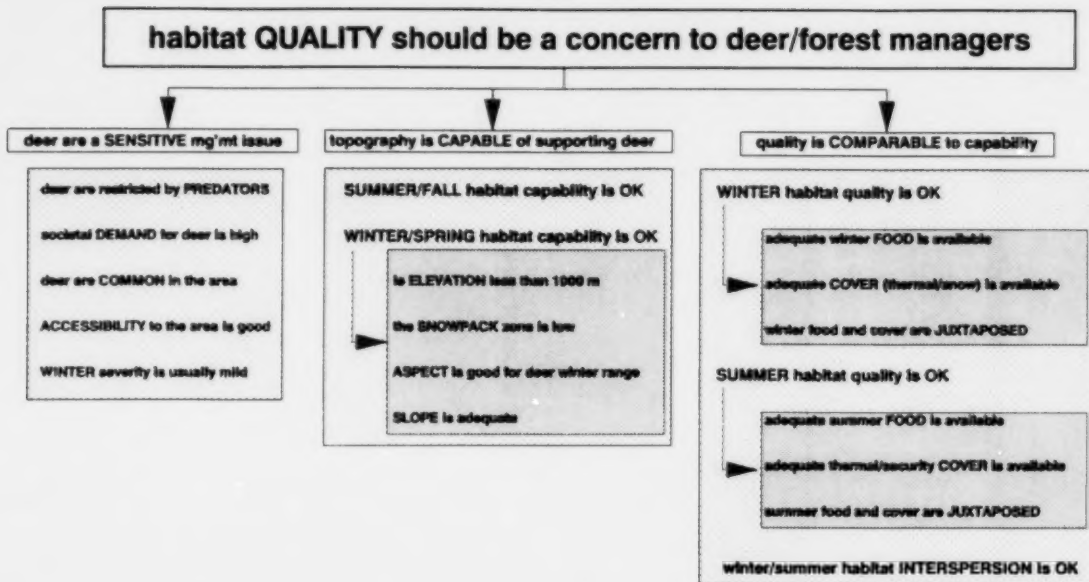


FIGURE 2. Regional priorities model structure.

The final priority rating is determined according to the limiting factor. If any of the three supporting hypotheses provide negative weight, then habitat management is not a concern. For instance, even though habitat quality is not comparable to capability, habitat management does not have high priority as an undertaking if the sensitivity of the deer management issue is very low.

To evaluate the regional priorities model, a test group (two managers and one research biologist) applied the model to two areas of approximately 1500 ha each. One area was familiar to all three users and one area was somewhat unfamiliar. All users were trained biologists and well aware of the concepts described in the model. Presumably, if the results varied dramatically among the users, it would indicate a problem with the model rather than simply a misinterpretation or a lack of understanding. The level of disagreement among the users was determined by adding the difference between the scores of all combinations of the three biologists (Figure 3).

In general, there was a high level of agreement. However, strong disagreement arose over the questions about predation and winter severity. This indicates that either the questions were poorly worded or that the users' world views differ on those topics. There was also disagreement about the value of cover and habitat juxtaposition as they relate to current habitat quality in the area that was relatively unfamiliar. This indicates that a more "data-driven" model may be required to assist users with little experience in the location being assessed.

We note the following conclusions about the regional model:

1. Frequently, the consultation with the regional model was difficult because of poor wording of the questions.
2. The question format was not sufficiently flexible to express adequately all of the questions.
3. The logic structure available with the Deciding Factor software was not sufficiently flexible to express realistically the relationships among the variables.
4. It would be advantageous to assist the user by providing him or her with the ability to query databases while within the consulting session.

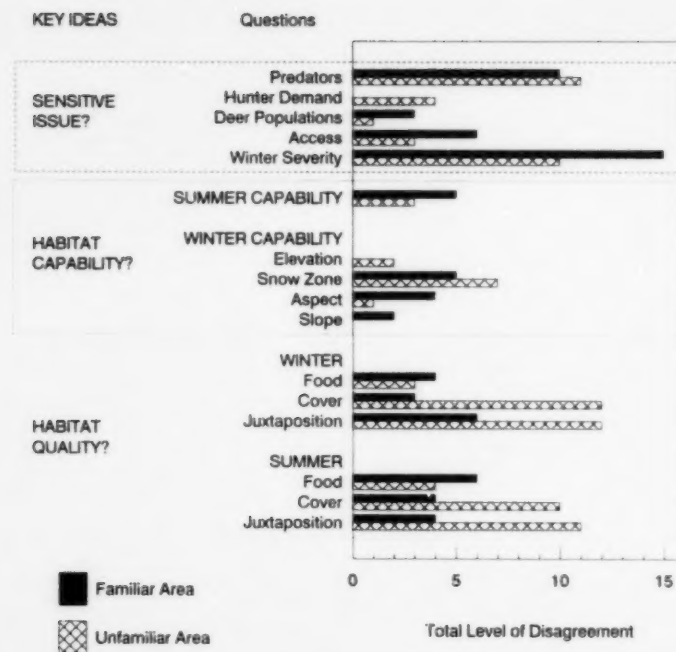


FIGURE 3. Level of disagreement among users who applied the regional priorities model to two small areas on Vancouver Island.

2.6.2 Watershed assessment model

The process of watershed assessment involves five steps:

1. evaluation of current habitat quality;
2. modification of land attributes (primarily forest age) based on one or more forest harvesting scenarios and forest succession;
3. re-evaluation of habitat quality at pre-determined time steps;
4. comparison of future habitat quality with objectives for habitat; and
5. modification of harvesting scenarios or recommendation of habitat enhancement procedures if future habitat quality does not meet objectives.

For the purposes of this example we describe the process and results associated with the first three steps for black-tailed deer winter habitat on an 11 000 ha study area on southern Vancouver Island. The study area has been the focus of deer habitat research and model development and is described by McNay and Doyle (1987).

Evaluation of current habitat quality requires a species habitat relationship model. Current development efforts are focused on modeling habitat quality during the winter season for black-tailed deer. That submodel (Figure 4) is based on the following premises.

Snowfall on Vancouver Island exhibits a highly variable pattern, with severe winters (persistent deep snowpack) recurring infrequently (at approximately 20-year intervals). Severe winter conditions (defined as a snowpack of 45 cm or greater, persisting for more than 30 days [Nyberg and Janz 1990]) occur with varying frequency throughout the island, depending on elevation. Therefore, for long-term population viability, black-tailed deer require access to habitats that will enable them to survive both mild and severe winter conditions. McNay and Doyle (1987) have found that accessibility of severe winter habitat is influenced by the migratory behavior of individual deer.

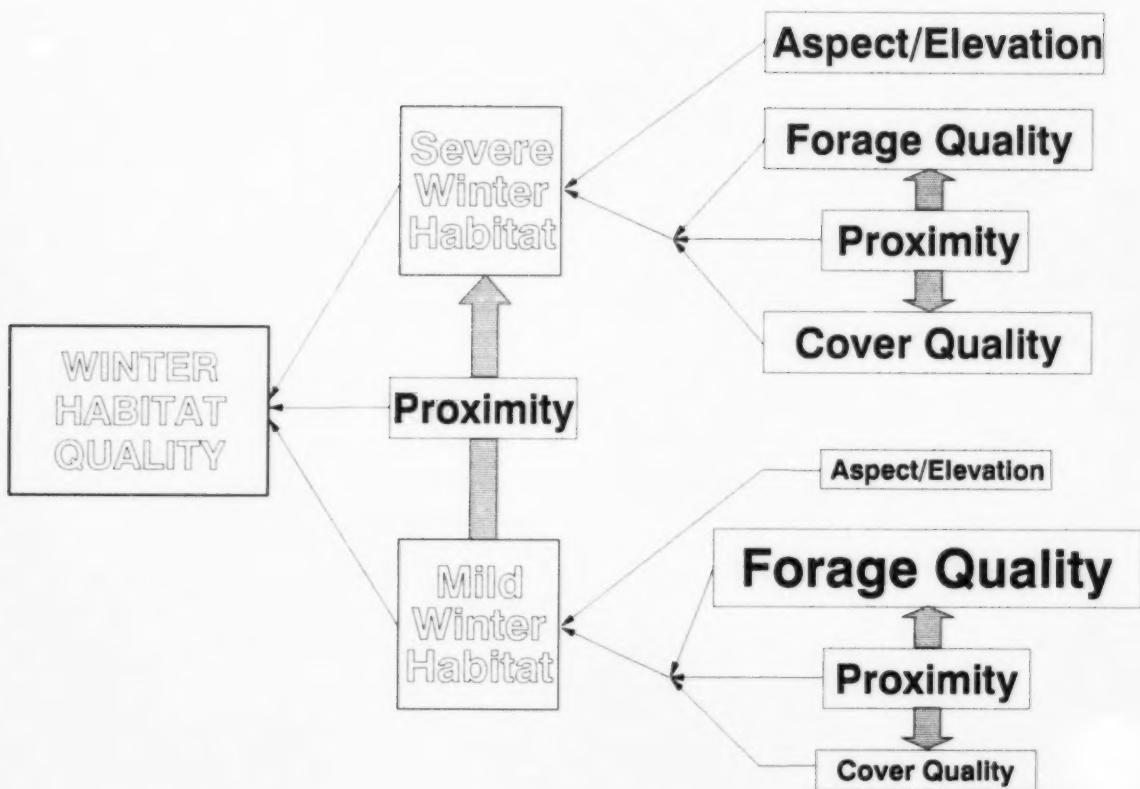


FIGURE 4. Black-tailed deer winter habitat suitability model structure.

Black-tailed deer exhibit three different migratory behaviors. Obligate migrators (individuals that move at the same time of year regardless of weather conditions) spend the winter in severe winter habitat. Therefore, for those deer, severe winter habitat must also be adequate mild winter habitat. Year-round residents (individuals that do not migrate) will move up to 0.75 km from mild winter habitat to severe winter habitat. Facultative migrators (individuals that move from summer to winter range, depending on day-to-day changes in weather conditions) will move up to 3.0 km from mild winter habitat to severe winter habitat (distances interpreted from McNay and Doyle 1987).

Within a single day, deer require food and cover (primarily stands that intercept snow, thus maintaining the availability of forage). We assume that the quality of habitat increases as the distance between these two attributes decreases. The habitat quality of a given location is also constrained by its aspect and elevation. High-elevation, north-facing slopes tend to receive more snow and retain it longer (i.e., lower quality) than do low-elevation, south-facing slopes (i.e., higher quality). The quality of a given location differs between years, and at different times within a winter, because deer require better snow interception cover during severe winter conditions than during mild winter conditions, and deer movements are more constrained by deep snow during a severe winter.

The model structure, described above, requires information on the current vegetation cover, aspect and elevation to be applied. Current vegetation cover in the study area was classified and mapped by Clements (1985) using the Biogeoclimatic Ecosystem Classification (BEC) method as described by Klinka *et al.* (1984). Aspect was mapped using visual interpretation of 1:50 000 National Topographic System (NTS) map sheets. Elevation was mapped directly from 1:50 000 NTS map sheets.

Application of the model structure requires that ratings be applied to the map-based information for the following variables:

- food quality of a location;
- snow-interception cover quality of a location;
- the proximity of a location to a location with high-quality food and a location with high-quality cover; and
- the aspect and elevation of the location.

Each BEC map polygon was rated from 0.0 to 1.0 for its ability to provide forage and its ability to provide snow-interception cover. These ratings (Figures 5 and 6) were based on three factors: biogeoclimatic variant, soil moisture regime, and stand age. Ratings were applied using the personal experience of deer biologists with the study area, and the known relationships among the three factors and understory herb and shrub production and canopy characteristics.

Ratings from 0.0 to 1.0 were developed for the proximity of a given location to locations that provide high-quality forage and high-quality mild winter and severe winter cover. Cutoffs for high-quality forage (Figure 5) and high-quality mild and severe winter cover (Figure 6) were arbitrarily assigned based on the judgement of deer biologists familiar with the area. "Distance buffers" were rated in terms of the likelihood that a deer would move that distance in shallow or deep snow (Figure 7). Ratings were based on the distributions of radio-telemetry locations of deer relative to distances from clearcut-cover edges (Kremsater 1989). Distance buffers around high-quality food and high-quality cover were automatically calculated and saved as separate map layers.

Combined aspect and elevation classes were also rated from 0.0 to 1.0 in terms of the constraints they placed on the ability of current vegetation cover to provide deer habitat (Figure 8). Ratings were based on judgments of field biologists familiar with black-tailed deer in the area.

The above ratings were used to calculate habitat quality values for mild and severe winter conditions:

$$Q_{sev} = (((1-(1-F)^{1.0} * (1-C)^{1.0})^{0.5})^{1.5} * FD^{0.75} * CD^{0.75})^{0.33} * AE^{1.0}$$

$$Q_{mld} = (((1-(1-F)^{1.0} * (1-C)^{0.4})^{0.5})^{1.5} * FD^{0.75} * CD^{0.75})^{0.33} * AE^{0.25}$$

where

- Q = the habitat quality value under mild winter conditions (mld) and severe winter conditions (sev);
- F = the food quality rating;
- C = the cover quality rating;
- FD = the rating for proximity to high-quality food ($F \geq 0.6$);
- CD = the rating for proximity to high-quality cover ($C \geq 0.1$ for Q_{mld} ; and $C \geq 0.7$ for Q_{sev}); and
- AE = the combined aspect/elevation ratings.

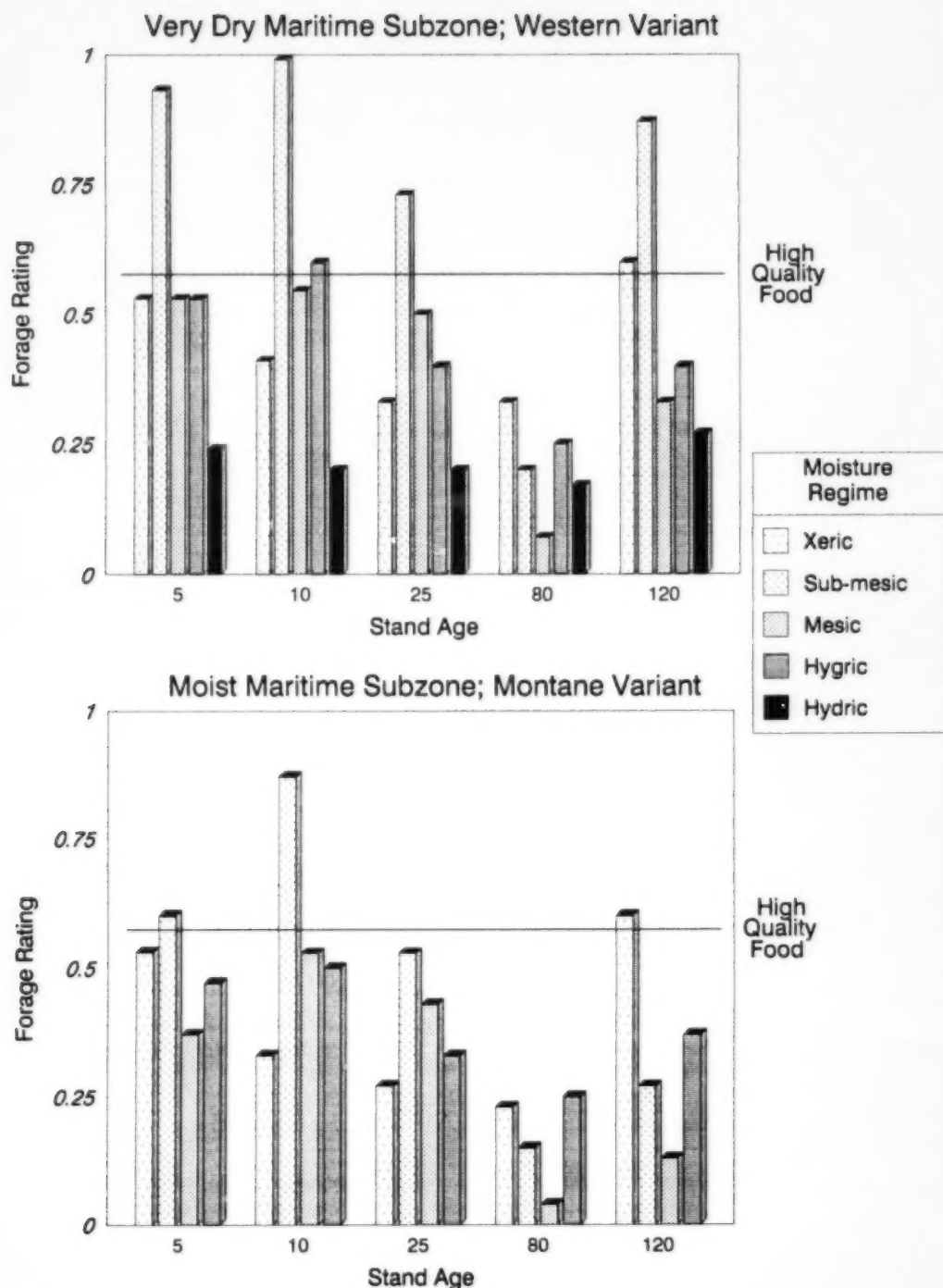


FIGURE 5. Forage quality ratings for the Coastal Western Hemlock variants that occur in the assessment area.

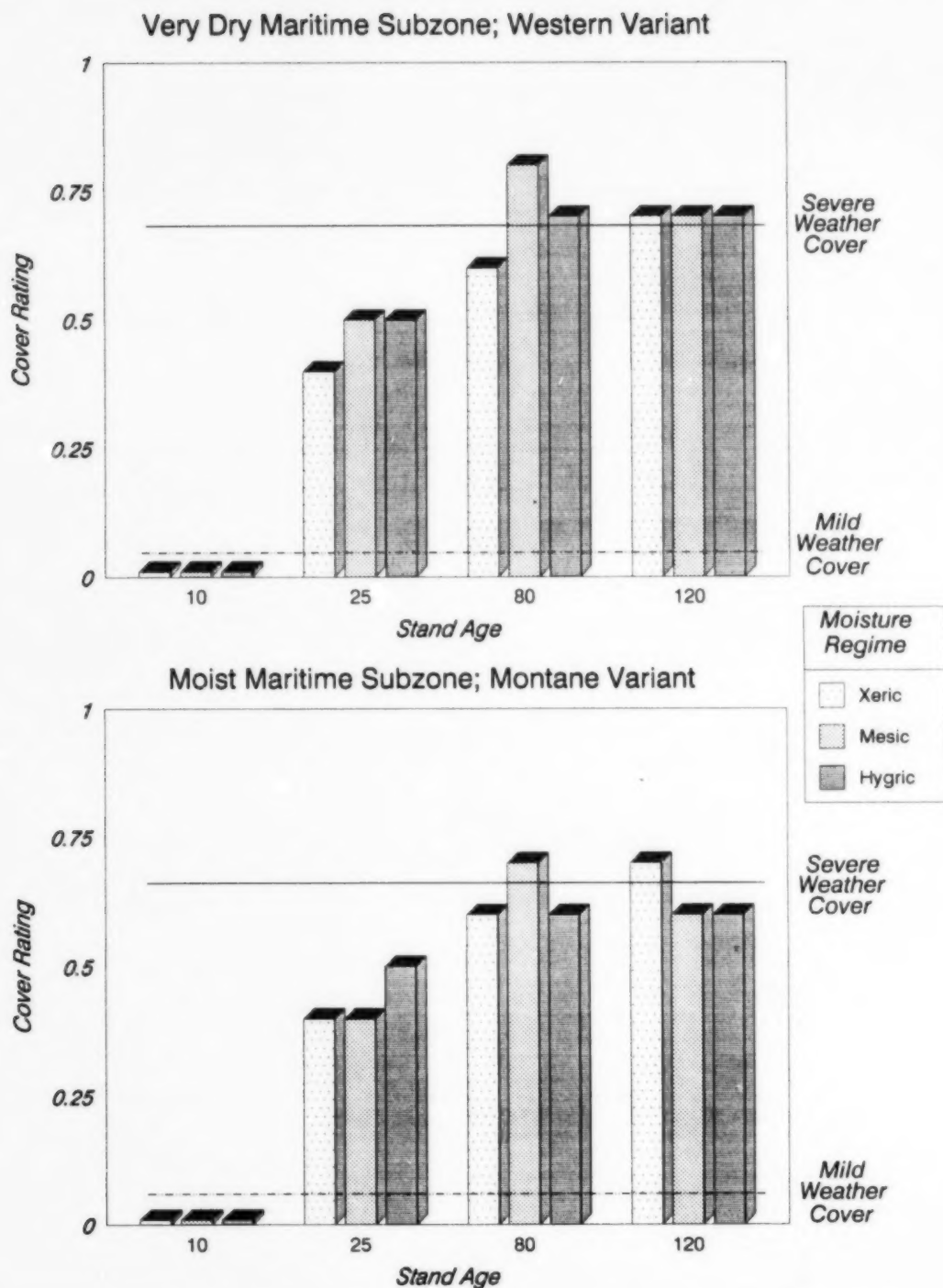


FIGURE 6. Cover quality ratings for the Coastal Western Hemlock variants that occur in the assessment area.

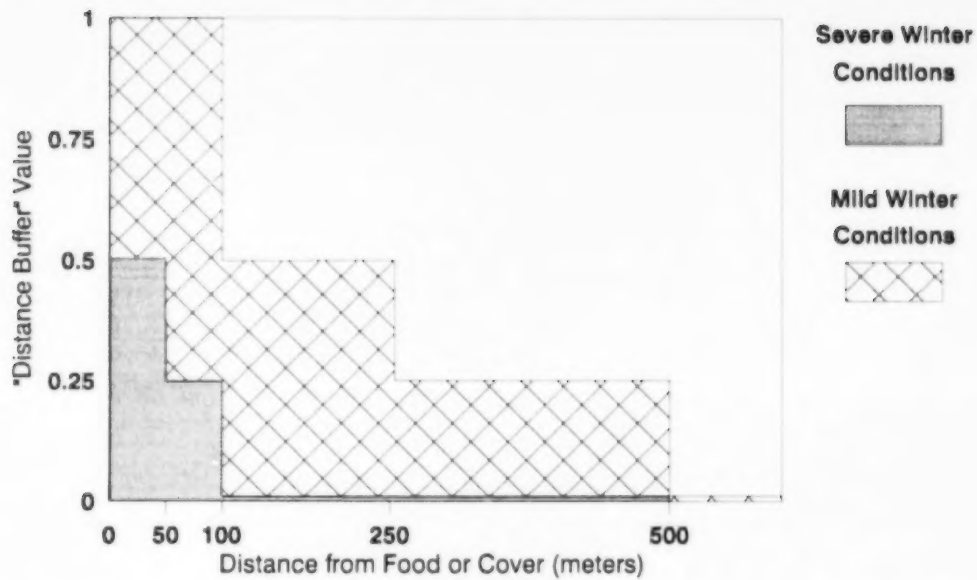


FIGURE 7. Ratings for distance from food and cover during mild and severe weather conditions.

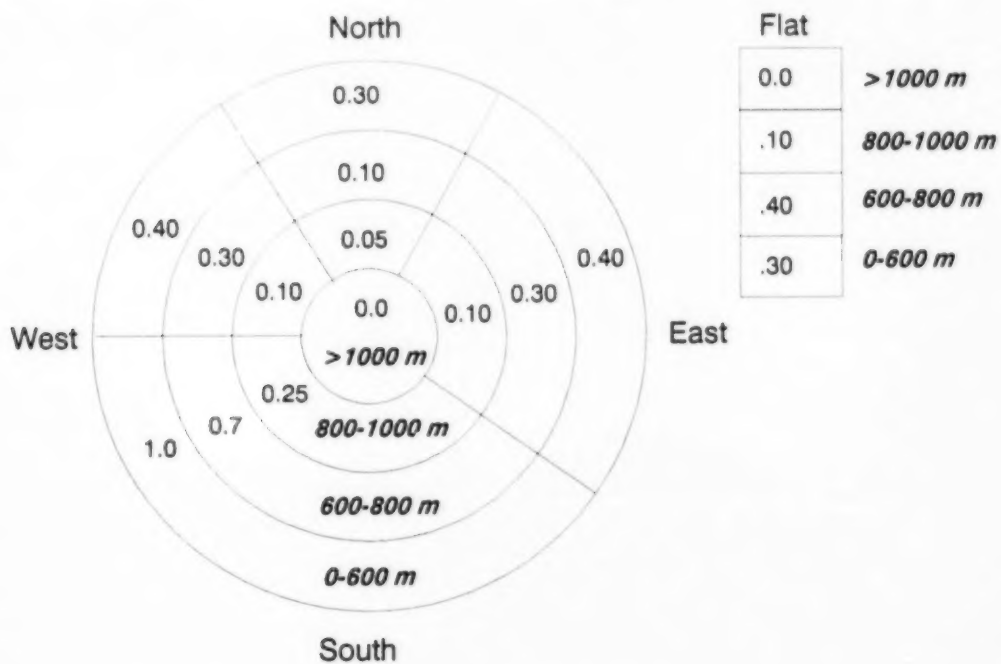


FIGURE 8. Ratings for combined aspect and elevation categories.

An inverse geometric mean of the food and cover ratings is used because if either value is high the location has the potential to be high-quality habitat if it also has high ratings for proximity (i.e., FD and CD). A weighted geometric mean of the food/cover value and the distance values (the "vegetation value") is used so that if any of these values is low, the resulting habitat value will be low. The "vegetation value" is multiplied by the aspect/elevation value because aspect/elevation represents a limiting factor on the overall habitat quality. The differences in weighting between Q_{sev} and Q_{mld} reflect the fact that snowfall, and thus snow-interception cover and aspect/elevation, are less of a concern during mild winter conditions than they are during severe winter conditions.

To create a composite winter habitat quality map, showing both the spatial arrangement of mild and severe winter habitats, each resultant habitat-quality polygon was categorized as adequate or inadequate mild winter and severe winter habitat. A habitat-quality value of 0.50 was used as the dividing line between adequate and inadequate habitat. Map layers representing adequate severe and mild winter habitat were then overlaid (Figure 9). Distance buffers around adequate severe winter habitat, which included adequate mild winter habitat within 0.75 km and 3.0 km, represent the migratory behavior types of black-tailed deer, as described above.

The map presented in Figure 9 represents the results of the first step in the watershed assessment process: evaluation of current habitat quality. Steps 2 and 3 involve imposing a harvesting scenario and reevaluating habitat quality after a pre-determined time step. For the purposes of this example, application of a hypothetical harvesting scenario was assessed, in which most of the remaining low-elevation old growth would be harvested between 1990 and 2010. The harvesting scenario was applied and the successional stage of each stand was changed to simulate conditions in the year 2020. A reassessment of winter habitat quality in 2020 was conducted using the methodology outlined above (Figure 10).

If the objective was to maintain the current quantity and distribution of winter habitat in 2020, then this objective would clearly not be met (see Figure 11 and compare Figure 9 and Figure 10). The habitat-quality model predicts that the amount of adequate severe winter habitat will not decrease substantially from 1990 to 2020 (Figure 11), even though most of the low-elevation old growth will be harvested. The reason is that the model predicts that new severe habitat will develop at the edges between old second growth (which provides cover) and younger stands (which provide food). An example of this "ring" or "buffer" around severe winter habitat is clearly visible in the northeastern corner of the map shown in Figure 10. However, the amount of inadequate mild winter habitat will increase from 50 to 64% of the assessment area during the planning period and the amount of habitat suitable for supporting facultative migrators will decrease substantially (Figure 11). In addition, deer winter habitat will be severely fragmented, particularly in the western portion of the assessment area.

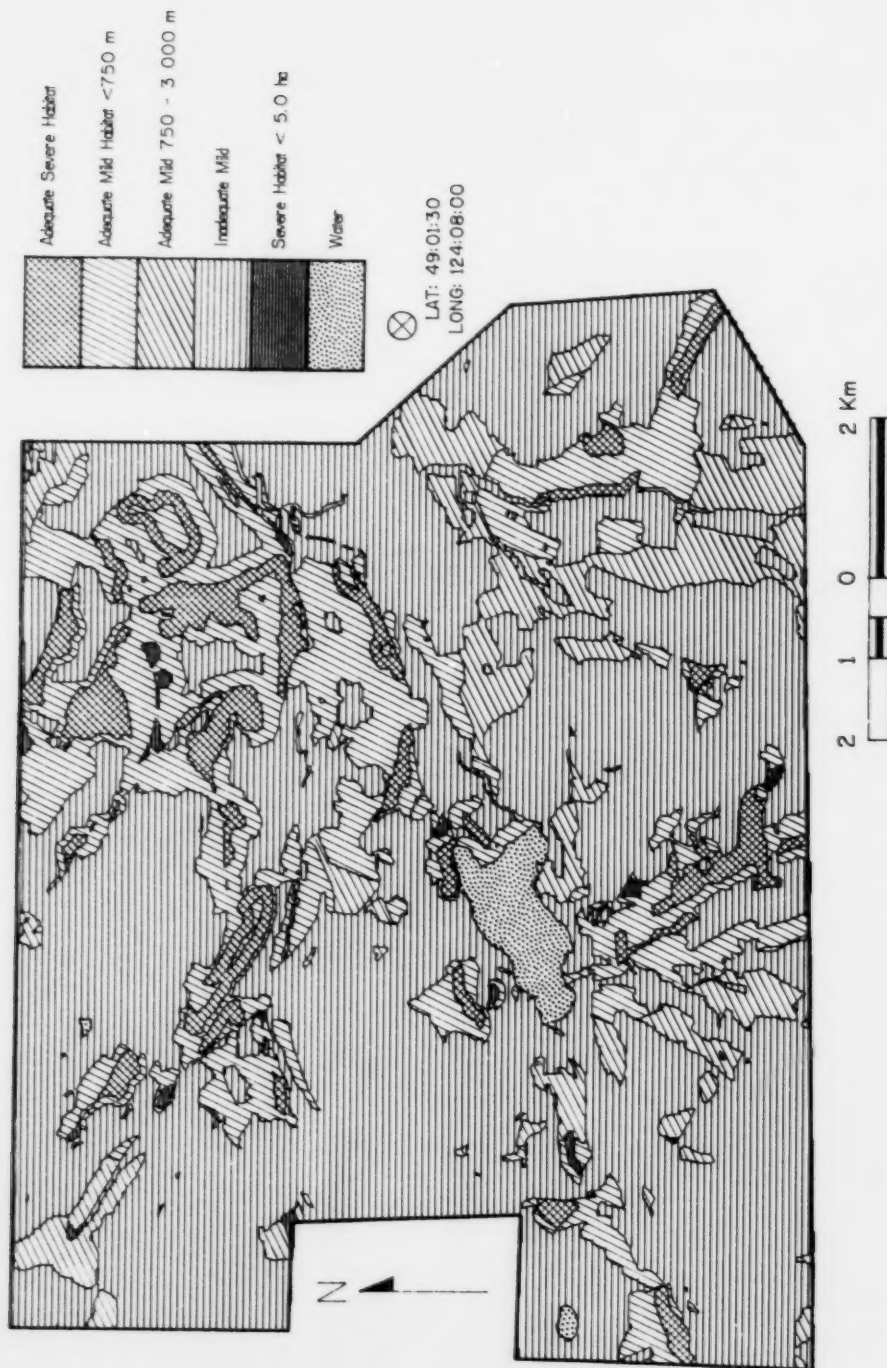


FIGURE 9. Current (year:1990) winter habitat suitability for black-tailed deer.

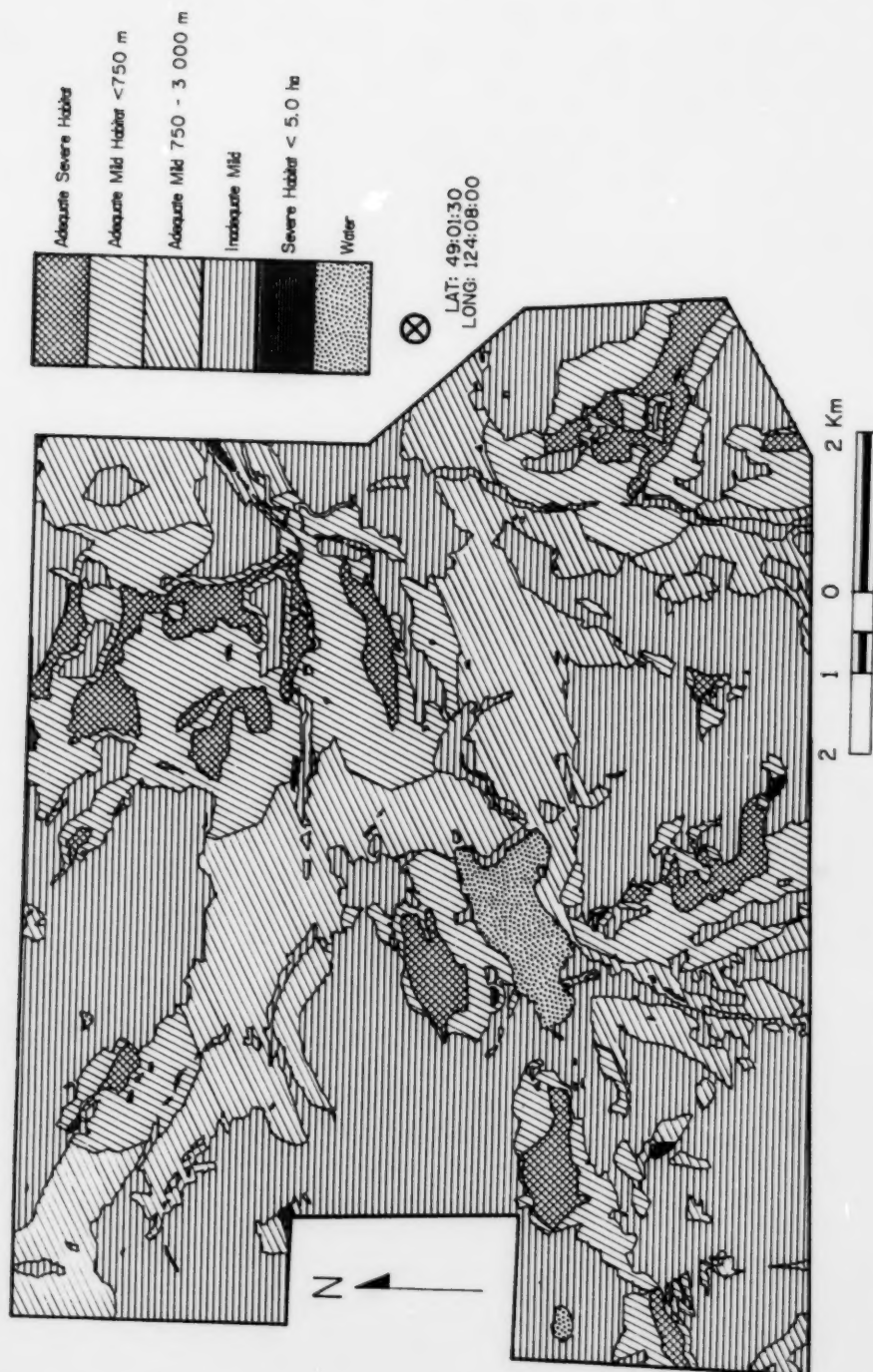


FIGURE 10. Projected (year:2020) winter habitat suitability for black-tailed deer.

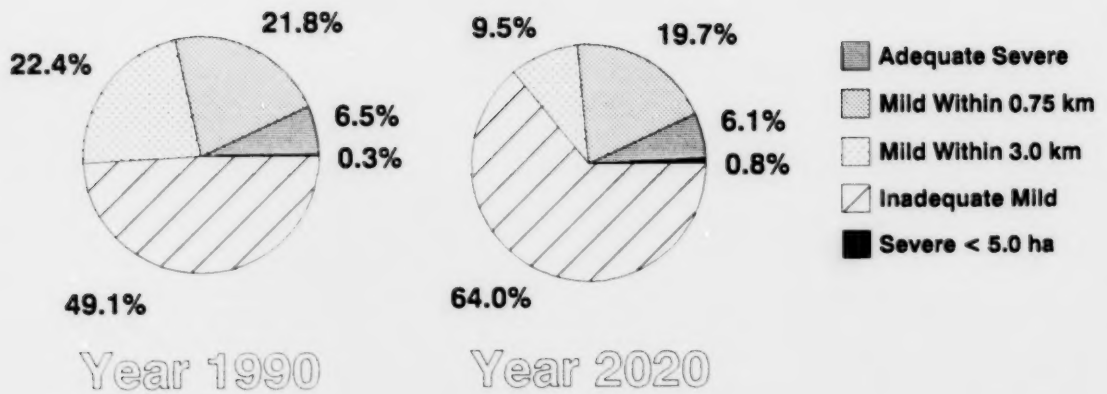


FIGURE 11. Summary of black-tailed deer winter habitat in the assessment area.

3 TOOL DEVELOPMENT AND IMPLEMENTATION

The HAP tool will be at the leading edge of technology, both in terms of integrated resource management (Nyberg *et al.* 1989) and geographic information systems (Coughlan and Olliff 1988). Users frequently have unrealistic expectations of leading-edge technology and these must be tempered by the very real limitations that may exist. Limitations result primarily from inadequacies in data and limited understanding of natural systems. Gaps in information and understanding may occur at various levels. For example:

1. Government policies may not be specific enough; e.g., what are the MOELP deer habitat/population objectives for individual watersheds or planning units?
2. Various models required by HAP (particularly in the fields of forestry and economics) may not be available; e.g., models of stand succession and growth for years 1 to 20 after harvesting.
3. Specific data may be unavailable and/or the nature of specific relationships may not be quantified; e.g., what is the minimum size of an effective severe winter range and does the size vary depending on snow zone?

It is well beyond the scope of the current project to fill in all of the existing gaps in information and understanding. Therefore, the "ideal" HAP tool and the HAP tool that can be constructed today are two very different things.

The process of developing and implementing the HAP tool will be driven or constrained by a number of factors:

1. There is a limited amount of manpower and money devoted solely to the HAP project. In addition, several other research projects are currently under way that can be of direct benefit to the HAP project: a handbook for managing deer and elk habitats (Nyberg and Janz 1990), field research on the ecology of deer movement patterns (McNay *et al.* 1988), an elk habitat relationship model validation,³ a simulation model for managing stands as deer winter range,⁴ and various other integrated resource management initiatives. It is therefore reasonable to schedule the development and implementation of the project to coincide with the completion of these other activities.
2. The major research program (Integrated Wildlife-Intensive Forestry Research [IWIFR]), of which the Habitat Assessment and Planning tool is a part, will come to an end 31 March 1991. Therefore, the tool development and implementation must be scheduled so that there is a deliverable product available at the end of the IWIFR program and that any post-IWIFR tasks can be justified on their own merits.
3. The HAP tool currently being developed is a prototype of a more generally applicable tool that could be used for any wildlife species in any geographical area. In addition, the HAP tool will support adaptive management activities. Therefore, the tool development, implementation, verification, and refinement are viewed as ongoing processes that will continue as long as the tool continues to demonstrate its utility.

The following discussion of development and implementation represents a compromise between the factors discussed above and the structured approach to systems planning and development advocated by Calkins (1984) and Stock (1988).

Stock (1988) advocates the development of a prototype early in the process of development of complex computerized decision-support systems. The prototype serves two purposes. First, it can be used to gain support from users and managers, who are often skeptical about the eventual success of the system, by demonstrating the utility of the overall system early in the development process. Second, if the development of the system is not completed, the prototype will be a useable product that can partially justify

³ Brunt, K. 1989. Application of a geographic information system (GIS) to test models of Vancouver Island Roosevelt Elk habitat suitability. M.Sc. thesis proposal. Univ. Victoria, Dep. Biology, Victoria, B.C.

⁴ Bunnell, F.L. and R. McLaughlin 1986. Second growth deer winter range simulation modelling. Proposal to Wildlife Habitat Canada. Unpubl. rep.

the development costs. Since the watershed assessment model forms the core of the HAP tool, this model will be used as the prototype. The prototype will be developed for black-tailed deer because of the preparatory work done on this model before the initiation of the HAP project.

The prototype will include the development of a complete habitat-quality model for black-tailed deer, including seasonal range quality submodels and a seasonal range juxtaposition submodel. The winter habitat quality submodel is described in Section 2.6.2. The summer habitat quality submodel will include the same factors as the winter submodel but relative weights of the factors will be different and the cover component will rate escape and thermal cover. The seasonal habitat interspersation submodel, will consist of the following:

1. the seasonal habitat quality, as derived from the habitat submodels discussed above;
2. the total area that provides adequate all-season habitat (year-round habitat for resident deer); and
3. the distance between "high-quality" single-season habitats.

Model parameters will be verified using existing data from the study area where the model was developed. Data required for the validation of the overall model and submodel outputs are being collected in a separate area (McNay and Morgan 1989). The model output (habitat quality) will be validated by comparing home-range data with the habitat quality ratings. Completion of the development of the prototype models is expected by December 1990. Validation of the model will not be complete until March 1991.

Development and implementation of the full HAP tool will require:

- refinement of the regional priorities model;
- development of the components of the management options model;
- extension and technical transfer of the completed tool; and
- testing of the reliability and validity of the overall tool output.

The strategy for completion of these tasks is briefly described below.

The original regional priorities model (McNay *et al.* 1987) will be improved and refined in several ways (based on the conclusions outlined in section 2.6.1):

1. The model will be reprogrammed using a more flexible expert system shell that allows questions to be asked and answered in ways that are most appropriate to the question's content.
2. The model will be linked to a variety of small-scale GIS databases that will assist the manager in answering the questions (e.g., on habitat capability, land tenure, and planning unit boundaries).
3. The model will provide automatic decision audit in a form that is transparent to the user.
4. The model will be verified through trial runs over large geographical areas with knowledgeable users.

It is anticipated that this task will be completed after the development of the watershed assessment model prototype (April 1990 to March 1991). Assessing the validity of the regional priorities model will require many years because of the nature of the model output.

The components of the management options models are largely being developed by other research projects (Nyberg and Janz 1990; Bunnell and McLaughlin⁵). These components will be incorporated into the HAP framework as they become available. However, site-specific planning is seen to be a secondary consideration of the HAP project and as a result the management options model will probably not be completed until after March 1991 (the deadline for completion of HAP).

Delivery of a useful operational tool to prospective users will require a substantial extension and technical transfer program. This will involve a two-step process. First, the utility of the tool will be demonstrated to the middle management personnel in the Habitat Protection Section of MOELP. This will

⁵ Bunnell, F.L. and R. McLaughlin 1986. Second growth deer winter range simulation modelling. Proposal to Wildlife Habitat Canada. Unpubl. rep.

be done by assisting these personnel with the application of the watershed assessment model to a particularly difficult or high-conflict problem that they are encountering. The same personnel will be assisted with the operation of the regional priorities tool to assess broad-scale priorities throughout their entire region. We hope that once these tasks are completed (March 1991), MOELP personnel will accept the utility of the tool and encourage its application by others in their ministry.

Training of the "line" personnel in the use of the tool will be a time-consuming process that will require specialized skills for the creation of user manuals and training courses and the delivery of those courses. Extension of the tool will also require the acquisition of required computer hardware and software for the "line" personnel. Managers must be aware that the process of extension and training will be time consuming and costly and will probably result in a decrease in productivity in the short term. It is anticipated that extension and training of the HAP tool will be completed by March 1993.

Testing of the reliability and validity of the overall tool output will be an ongoing process that will continue as long as the tool is used. Management recommendations will be made based on the tool output, and it will take many years in some cases to determine whether those recommendations were correct. For this reason, a major emphasis in the tool construction will be placed on good decision audit mechanisms. For example, the watershed assessment model will have the ability to maintain a database that will include all of the information about a given cutblock in a forestry plan, including field reconnaissance information, in-house discussions, and recommendations and letters sent to the timber company or the B.C. Forest Service. This database will be useful in day-to-day operations for reviewing updated versions of plans and preparing ministry referrals. However, it will also be useful to the future assessment of the utility of recommendations based on the model output.

4 LITERATURE CITED

- B.C. Ministry of Environment and Ministry of Forests. 1983. Reservation of old-growth timber for the protection of wildlife habitat on northern Vancouver Island. B.C. Min. For., Inf. Serv. Br., Victoria, B.C.
- Calkins, H.W. 1984. A pragmatic approach to geographic information system design. *In* Basis reading in geographic information systems. D.F. Marble, H.W. Calkins and D.J. Peuquet (editors). SPAD Systems Ltd., Williamsville, N.Y., pp. 6.1-6.13.
- Clements, C. 1985. Ecosystematic units of the south Nanaimo River deer study area. Map research and production for the Integrated Wildlife - Intensive Forestry Research program. B.C. Min. Environ. and Min. For. Victoria, B.C.
- Coughlan, J.C. and T. Olliff. 1988. Geographic information systems: an introduction for natural resource managers. *Western Wildlands* 14:20-24.
- Dellert, L. and D.H. Williams & Associates Ltd. 1989. AFIRM: analysis framework for integrated resource management. B.C. Min. For., Inventory Br., Victoria, B.C.
- Dunbar, M.J. 1980. The blunting of Occam's razor, or to hell with parsimony. *Can. J. Zool.* 58:123-128.
- Harcombe, A. and T. Baker. 1987. Integrated wildlife intensive forestry research program: Phase 2 blueprint. B.C. Min. Environ. Parks and B.C. Min. For. Lands, Victoria, B.C. 14 p.
- Heinen, J. and G.H. Cross. 1983. An approach to measuring interspersions, juxtaposition and spatial diversity from cover type maps. *Wildl. Soc. Bull.* 11:232-237.
- Hilborn, R. 1987. Living with uncertainty in resource management. *N. Am. J. Fish Manage.* 7:1-5.
- Hofstadter, D. 1979. Goedel, Escher, Bach: An eternal golden braid. Basic Books, New York, N.Y. 481 p.
- Klinka, K., R. Green, P. Courtin, and F. Nuszdorfer. 1984. Site diagnosis, tree species selection, and slashburning guidelines for the Vancouver Forest region. B.C. Min. For., Victoria, B.C. Land Manage. Rep. No. 25. 180 p.
- Kremsater, L. 1989. The influences of habitat interspersions on habitat use by Columbian black-tailed deer. M.Sc. thesis. Univ. B.C., Fac. For., Vancouver, B.C.
- Leopold, A. 1933. Game management. Charles Scribner and Sons, New York, N.Y. 481 p.
- Lyon, J.G., J.T. Heinen, R.A. Mead, and E.G. Roller. 1987. Spatial data for modelling wildlife habitat. *J. Survey Engineering* 113:88-99.
- McNay, R.S. and D.D. Doyle. 1987. Winter habitat selection by black-tailed deer on Vancouver Island: a job completion report. B.C. Min. Environ. Parks and B.C. Min. For. Lands, Victoria, B.C. IWIFR-34. 91 p.
- MacNay, R.S., D.D. Doyle, and R.E. Page. 1988. The spatial and temporal factors of managing black-tailed deer habitat: a research working plan. B.C. Min. Environ. and B.C. Min. For., Victoria, B.C. IWIFR-37. 52 p.
- McNay, R.S. and J. Morgan. 1989. Habitat Assessment and Planning: understanding the implications of deer movement patterns. Working Plan Proposal No. 89.02 to South Moresby Forest Replacement Account. B.C. Min. For., Victoria, B.C. 21 p.
- McNay, R.S. and R.E. Page. 1988. Integrating wildlife and forest management using a GIS. *In* Geographic information and land resource analysis. Proc. 12th Land Resource Science Workshop, February 18-19, 1988, Vancouver, B.C.
- McNay, R.S., R.E. Page and A. Campbell. 1987. Application of expert-based decision models to promote integrated management of forests and deer. *Trans. 52nd N. Amer. Wildl. Nat. Res. Conf.* 52: 82-91.
- Nyberg, J.B. and D.W. Janz. 1990. Deer and elk habitats in coastal forests of southern British Columbia. B.C. Min. For., Victoria, B.C. Special Rep. Series No. 5.

- Nyberg, J.B., R.S. McNay, M. Kirchhoff, R. Forbes, F. Bunnell, and E. Richardson. 1989. Integrated management of timber and deer: coastal forests of British Columbia and Alaska. USDA For. Serv., Pac. Northwest Res. Sta., Portland, Oreg. Gen. Tech. Rep. PNW-GTR-226. 65 p.
- Reid, R. 1985a. The value and characteristics of resident hunting. B.C. Min. Environ., Wildl. Br. Victoria, B.C. 153 p.
- . 1985b. The value and characteristics of non-resident hunting. B.C. Min. Environ., Wildl. Br. Victoria, B.C. 183 p.
- Reid, R., M. Stone, and F. Rothman. 1985. Report of the British Columbia survey of wildlife activities for 1983. B.C. Min. Environ., Wildl. Br. Victoria, B.C. 152 p.
- Stock, M. 1988. Planning expert system projects. A.I. Applications 2:9–15.
- Walters, C. 1986. Adaptive management of renewable resources. Macmillian Publishing Company, New York, N.Y. 374 p.

5



Applying Geographic Information Systems to Support Comprehensive Land Management Planning: Experiences of the Tongass National Forest, Alaska

Lowell H. Suring
Alaska Region
USDA Forest Service
Juneau, Alaska

Eugene J. Degayner, III
Tongass National Forest
USDA Forest Service
Juneau, Alaska

William H. Wilson, Jr.
Alaska Region
USDA Forest Service
Juneau, Alaska

TABLE OF CONTENTS

1	THE ISSUE	116
2	THE SETTING	116
3	DEVELOPMENT OF THE TONGASS LAND MANAGEMENT PLAN, 1977 TO 1979	117
3.1	Timber	117
3.2	Wildlife	118
3.3	Application of Information	118
4	IMPLEMENTATION OF THE TONGASS LAND MANAGEMENT PLAN, 1979 TO 1989	121
5	REVISIONS OF THE TONGASS LAND MANAGEMENT PLAN, 1989	122
5.1	Evaluation of Data Management Strategies	122
5.2	Implementation of GIS	123
5.3	Management of Data in GIS	123
5.3.1	Sliver polygons	123
5.3.2	Grid cells	125
5.4	Application of GIS	126
5.4.1	Wildlife	126
5.4.2	Land suitable for timber harvest	132
6	CONCLUSIONS	135
	LITERATURE CITED	136

FIGURES

1	Comparison of time required for preparation of data and analysis for manual and automated information systems	123
2	The effect of eliminating polygons ranging in size from 0.5 to 20 ha on average polygon size, number of polygons, and total area	125
3	The effect of eliminating polygons ranging in size from 0.5 to 20 ha on proportion of inventoried area that is reclassified	126
4	The effect of grid density on number of grid cells	127
5	The effect of grid density on computer space required for storage	127
6	Computer processing required to develop data files for analysis purposes	128
7	Process for incorporating management indicator species and associated habitat capability models into the planning process	129
8	Process for identifying lands suitable for timber production in the Tongass National Forest of southeast Alaska	133

TABLES

1	Description of variables used to describe data points during resource inventory for development of the Tongass Land Management Plan	119
2	Description of variables used to rate Value Comparison Units for wildlife values for development of the Tongass Land Management Plan	120
3	Mapped information required for the revision of the Tongass Land Management Plan	124
4	The effect of eliminating polygons on the number of remaining polygons per quadrangle map	125
5	Wildlife management indicator species being used in the revision of the Tongass Land Management Plan	128
6	Variables included in the GIS used to model habitat capability for the management indicator species for revision of the Tongass Land Management Plan	130
7	Application of the habitat capability model for Sitka black-tailed deer on the Kadashan Quadrangle in southeast Alaska	132
8	Inventories available in the GIS that were used to define lands tentatively suitable for timber production in the Tongass National Forest of southeast Alaska	133
9	Classification of lands suitable for timber production in the Tongass National Forest of southeast Alaska	134

1 THE ISSUE

Management of the Tongass National Forest, which includes nearly 97% of the land in southeast Alaska, requires a comprehensive land management planning process to ensure all concerns are addressed in the formation of management strategies. The USDA Forest Service attempted to address issues involving the management of timber and wildlife on the Tongass National Forest through development of the original Tongass Land Management Plan (TLMP) from 1977 through 1979. In many cases, implementation of the plan did not resolve issues. The TLMP is currently undergoing a major revision. Addressing issues involving wildlife and timber management and incorporating them into the analysis and decision process again provides a major challenge to the USDA Forest Service.

The availability of comprehensive information describing the resources to be managed is probably the most critical element in the development of land management plans. Accurate information that can be accessed easily may be the determining point between a plan that is implemented consistently and efficiently or one that becomes a meaningless document. The first case will help to assure that resources are well managed in response to the public's desires. The second case will cause confusion and mistrust of the managing agency and may result in mismanagement of resources.

We will discuss how the USDA Forest Service has responded to this challenge in planning for the management of the Tongass National Forest. We will briefly present procedures and process for managing natural resource information during the original development and the implementation of the TLMP over the last 10 years. We will also describe the development and use of an automated Geographic Information System (GIS) used to support the current revision of the TLMP. This discussion provides some insights into the potential advantages and pitfalls that may be associated with implementing a GIS to support planning and management elsewhere.

2 THE SETTING

Southeast Alaska is characterized by numerous islands and peninsulas, with intervening saltwater channels, bays, and inlets with approximately 21 000 km of coastline. Vegetation communities in this area include upland old-growth forests of western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) with scattered red cedar (*Thuja plicata*) and Alaska cedar (*Chamaecyparis nootkatensis*). These forests are interspersed with estuaries, riparian areas, muskeg openings with scattered shore pine (*Pinus contorta*), subalpine forests of mountain hemlock (*Tsuga mertensiana*), and alpine areas. These habitats support over 350 species of birds and mammals (Sidle and Suring 1986), including the densest breeding population of bald eagles (see Table 5 for scientific names of animals) and brown bears in the world. Several species which are endangered elsewhere in North America still flourish in southeast Alaska. Uses of wildlife include sport and subsistence hunting, trapping, and observation/photography. An expanding tourist industry has contributed to an increasing demand for opportunities to watch and photograph wildlife. This area also supports a substantial timber industry through timber harvest from private and federal lands.

The Tongass National Forest is the largest National Forest in the U.S. National Forest System, at 6860000 ha. The Tongass National Forest is managed under the multiple-use policy of the USDA Forest Service. This includes management to enhance use of the forest for recreation, wildlife, fisheries, and timber production. Management activities include development and maintenance of trails and cabins, implementation of fisheries enhancement projects, and timber harvest. Since the forest is so large, it is divided into three administrative areas, with Forest Supervisors offices in Ketchikan, Petersburg, and Sitka. Each supervisor's office has from two to four Ranger Districts under its administration.

In an attempt to encourage the establishment of a stable year-round industry in this area, long-term timber sale contracts were implemented in the 1950's. Two of these contracts are still in effect. The *Alaska National Interest Lands Conservation Act* requires the USDA Forest Service to make 10.6 million m³ of

timber available from the Tongass National Forest to the timber industry. On an annual basis, 703 000 m³ is offered to companies holding the long-term contracts and 360 000 m³ is offered under short-term sales (USDA Forest Service 1988a). The timber management program, with its associated road construction, is the most controversial management program in the Tongass National Forest. The controversy includes the impact of clearcut harvest practices on wildlife resources, the long-term nature of the timber sale contracts, and the costs associated with implementing the timber harvest program.

Most species of wildlife in southeast Alaska, including Sitka black-tailed deer, brown bear, bald eagle, Vancouver Canada goose, and hairy woodpecker have adapted to and rely on habitats provided by uneven-aged, old-growth forests (Lebeda and Ratti 1983; Schoen *et al.* 1984, Hughes 1985; Sidle *et al.* 1986; Peek *et al.* 1987). The conversion of old-growth forest to even-aged, second-growth forest through clearcutting dramatically changes ecological relationships and results in the reduction of habitat capability for most wildlife species (Schoen *et al.* 1988). The issue has been raised that timber harvesting, as currently practiced, will decrease the availability of wildlife resources for subsistence, sport, and commercial uses (USDA Forest Service 1989).

Issues regarding the long-term timber sale contracts have also been expressed. Some of the public believe there is a continued need for these contracts to ensure a steady, predictable, long-term timber supply upon which the timber industry can base its management decisions (USDA Forest Service 1989). Others feel that continuation of the long-term contracts does not give the USDA Forest Service enough latitude to address other resource issues and change management emphasis.

The costs associated with selling timber on the Tongass National Forest have recently exceeded revenue from the sales. This practice is supported by those people who believe that deficit sales are appropriate to maintain local economies. Others feel that timber that cannot be harvested economically should not be considered as part of the harvest base.

Road construction and maintenance activities in southeast Alaska are closely associated with timber harvest. Under some circumstances, these roads have increased the opportunities for the management of other resources and subsistence and recreational use of wildlife and fish. Other roads have resulted in concentration of use and increased competition for recreation, wildlife, and fish resources. In response to these varying results, some people favor additional roads and connection of existing roads; others oppose additional roads and feel existing roads should be closed to protect remaining wildlife populations and maintain the primitive character of Alaska.

3 DEVELOPMENT OF THE TONGASS LAND MANAGEMENT PLAN, 1977 TO 1979

Limited information was available to describe the resources in the Tongass National Forest in 1977. Five task forces were assembled to evaluate information available to them and determine how that information could be used to assist in the analysis of management options. The five task forces were land type/timber, minerals, wildlife, fisheries, and recreation/wilderness (Environmental Systems Research Institute 1984).

The forest was divided into 867 Value Comparison Units (VCU's) to provide common areas for the inventory and analysis of resources. These units are distinct geographic areas whose boundaries, in most cases, follow watershed divides. Occasionally, an island or group of islands constituted a VCU. The VCU's average 7300 ha, ranging from a few thousand hectares to hundreds of thousands. They were designed to provide a basis for describing and interpreting all resources.

3.1 Timber

A systematic point sampling technique was implemented to describe each VCU's potential yield of timber (USDA Forest Service 1978a). Approximately 210 000 sample points were selected and manually located on aerial photographs of the forest, using a grid. Each individually numbered point represented about 32 ha of land. About 0.5 ha around each sample point was analyzed through photo interpretation techniques for

several variables (Table 1) and verified with existing information. These site descriptions were then assigned to the entire 32-ha plot. Information assigned to the plots concerning visual sensitivity and wildlife habitat that may have affected timber harvest were provided by the recreation/wilderness and wildlife task forces. All information was entered manually on data forms.

The resource information associated with each sample point was entered into a remote hierarchical database and summaries generated by VCU. This information was then used to evaluate the timber supply and availability for each VCU relative to the others. A 0 to 5 ranking scale was used.

This effort led to the development of the most complete inventory of land type and timber data to that date. It was the first time that uniform data were available for the total forest. However, accuracy was limited by lack of field verification and by the potential lack of uniformity in interpretation of information from aerial photography.

3.2 Wildlife

The wildlife task force did not use the sample point inventory compiled by the landtype/timber task force to evaluate the habitat in each VCU. The wildlife task force selected 11 species and species groups upon which to base the assessment (USDA Forest Service 1978b). Information on the habitat relationships and range of each species was compiled from existing literature, survey data, personal experience, and professional judgment (Table 2). This information was recorded on maps of the forest. Overlays with VCU boundaries were placed over these maps and a value was assigned to each VCU for each species or species group and their habitat. These values were summed by VCU and the totals used to assign a rating of 1 to 5 for each VCU. The highest ratings tended to reflect the VCU's with the highest species and habitat diversity. Estimates were also made, by VCU, of the proportions of old growth needed to maintain viable populations of wildlife.

The reliability of this information varied with the remoteness of the area. The more remote sites were visited less often, so less survey and personal information was available. The best information was available for the major islands and major mainland river systems; the weakest information was for upland mainland areas.

3.3 Application of Information

The information generated to describe the timber and wildlife resources on the Tongass National Forest through this process was integrated throughout the planning process and in planning documents associated with development of the land management plan (USDA Forest Service 1979). The affected environment was described using the information generated (e.g., distribution of wildlife and wildlife habitat, proportion of VCU's with high and low value rankings for wildlife, area of commercial forest land [CFL], and proportion of CFL in each operating class).

Planning was facilitated by developing four Land Use Designations (LUDs) that specified management for wilderness (LUD I), primitive environment (LUD II), combination of commodity and amenity values (LUD III), and intensive development of commodity resources (LUD IV). Management alternatives were developed by evaluating the rankings of the VCU's for timber, wildlife, and other resources and then assigning high and low value VCU's to each of the LUD's in different combinations. Alternatives were evaluated in the effects analysis using inventory information for wildlife and timber (e.g., area of specific wildlife habitats by LUD; proportion of VCU's, by wildlife rankings, in each LUD; area of CFL in each LUD; and proportion of VCU's, by timber ranking, in each LUD).

TABLE 1. Description of variables used to describe data points during resource inventory for development of the Tongass Land Management Plan (USDA Forest Service 1978a)

Variable	Descriptors
Land type	Private land Censused freshwater (>16 ha) Non-censused freshwater (>16 ha) Estuary Muskeg Alluvial Valley bottoms and lowlands Glaciated valley walls Alpine Native land selection Other withdrawals
Timber land class	Commercial forest land (CFL) Noncommercial forest land Nonforest
Forest type (CFL)	Hemlock-spruce Cedar Red alder Black cottonwood
Stand size class	Unstocked Seedlings and saplings (diameter at breast height [DBH] ≤13 cm) Pole timber, (DBH >13 cm, ≤28 cm) Young growth sawtimber (DBH >28cm, ≤150 years old) Old growth (>150 years old)
Volume class	< 47 m ³ /ha 47–117 m ³ /ha 117–175 m ³ /ha 175–292 m ³ /ha >292 m ³ /ha
Site index	Low (55–85) Medium (85–115) High (115–150)
Slope class	0–40% 40–66% 66–75% >75%
Soil hazard	None Moderate Extreme
Harvest operability	Normal log operation (high-lead, tractor, skidder, single-span skyline, A-frame, deck and cable swing) Non-standard (multi-span skyline, helicopter, balloon, slackline) Inoperable
High/medium visual sensitivity	Marine highway Other boats Roads and trails Other recreation sites Areas associated with communities Administrative sites
Special areas	Research natural areas Historic and archeological areas Research area Wilderness study area Proposed wilderness study area Islands <20 ha Islands 20–120 ha
Wildlife habitat	Brown/black bear Beach fringe (300 m) Estuarine/upland grasslands (300 m buffer) Riparian (150 m buffer) Subalpine Gray wolf Denning/rendezvous areas (400 m buffer) Sitka black-tailed deer Intermediate winter range Winter range

TABLE 1. (Cont'd.)

Variable	Descriptors
Wildlife habitat	Moose Prime habitat/concentration areas Mountain goat Concentration areas, summer range, winter range Furbearers Forest habitat Beach fringe (180 m) Land birds Present Water birds Nesting, feeding, moulting, and concentration areas Bald eagle One nest every 3220 m or more One nest every 1610 to 3220 m One nest every 1610 m or less

TABLE 2. Description of variables used to rate Value Comparison Units for wildlife values for development of the Tongass Land Management Plan (USDA Forest Service 1978b)

Variable	Rating - Descriptors
Brown bear/black bear	0 - Absent 1 - Present 2 - Beach fringe 3 - Estuarine/upland grass flats - Stream sides - Subalpine - Inland grasslands
Gray wolf	0 - Absent 1 - Present 2 - Salmon streams, large tidal flats, travel routes, big game concentration areas
Sitka black-tailed deer	0 - Absent 1 - Present 2 - Intermediate winter range 3 - Winter range
Moose	0 - Absent 1 - Occasional use areas 2 - Viable population areas 3 - Prime habitat and concentration areas
Mountain goat	0 - Absent 1 - Occasional use areas 2 - Viable population ranges 3 - Concentration areas, summer range, and winter range
Furbearers	0 - Absent 1 - Occasional use areas 2 - Forest habitat except beach fringe 3 - Beach fringe - Islands (< 20 ha) - Major rivers - Lakes
Marine mammals	0 - Absent 1 - Occasional use areas 2 - General shoreline 3 - Concentration areas - Rookeries - Hauling grounds - Feeding and resting areas
Land birds	0 - Absent 1 - Uniform habitat types 2 - Mixed upland habitat 3 - Mixed habitat adjacent to marine waters, inland waters, or alpine
Water birds	0 - Absent 1 - Occasional use areas 2 - General shoreline

TABLE 2. (Cont'd.)

Variable	Rating - Descriptors
Water birds	3 - Nesting, feeding, moulting, and concentration areas
Bald eagle	0 - Absent 1 - One nest every 3220 m or more 2 - One nest every 1610 to 3220 m 3 - One nest every 1610 m or less

4 IMPLEMENTATION OF THE TONGASS LAND MANAGEMENT PLAN, 1979 TO 1989

Contiguous VCU's were grouped into 141 separate management areas to provide management direction to specific geographic areas (USDA Forest Service 1984). Management areas contained one or more VCU's allocated to a single LUD or to a combination of LUD's III and IV. Management areas ranged in size from a few thousand hectares to nearly a million hectares. Analysis of the management areas at the prescription level was to result in standards and guidelines that would refine the management direction specified in the TLMP. Project planning and design which incorporated these standards and guidelines was to occur at the implementation level.

However, forest-wide direction for Management Area Analysis (MAA) was not implemented. This resulted in MAA efforts on the three administrative areas that were inconsistent in approach and sporadic in action. Validation and updating of information used in development of the TLMP was to have taken place during MAA. This has not been accomplished, mainly because the sample point inventory and other information were not designed for use in project planning and were rarely used. Generally, during MAA and project planning, resource specialists manually prepared a series of maps that reflected timber types, specific habitats, timber operability, and prescriptions. These were then overlayed and evaluated to determine the best implementation of project activities to meet public expectations.

Although this approach was occasionally successful, it was recognized that well-structured and sound data were required for meaningful development and analysis of management actions (Environmental Systems Research Institute 1984). There was a lack of direction about what data should be collected and how they should be analyzed and presented. Protocols for data storage, presentation and documentation were inconsistent, undeveloped, or unenforced. Duplicate sets of data were maintained because of long delays and lack of confidence associated with data storage in the remote computer center. These problems demonstrated that standardized procedures for data collection, defined methods and formats for data storage, and a well-designed process for data access, sharing, and retrieval were needed. Specific to planning, enhanced capabilities were needed to perform overlays of resource maps and to produce area calculations, tabular reports, and final map products.

5 REVISIONS OF THE TONGASS LAND MANAGEMENT PLAN, 1989

Current legislation and the focus of attention on the management of National Forests, especially the Tongass National Forest, require that the USDA Forest Service effectively use available information to ensure that management issues are adequately addressed in the revision of the TLMP. Comprehensive inventories of soils and vegetation had been completed since the initial development of the TLMP. These inventories provided the opportunity for a comprehensive evaluation of resources on the forest if they could be effectively incorporated into the planning process.

5.1 Evaluation of Data Management Strategies

The need for an effective system for managing information to support the revision of the TLMP led the USDA Forest Service in the Alaska Region to implement a Natural Resource Management Information Needs Study conducted by Environmental Systems Research Institute (ESRI). The purpose of the study was to evaluate the information structure of the Tongass National Forest in order to recommend methods to efficiently manage information generated and used by the USDA Forest Service.

The ESRI study led to three basic alternatives relative to database design and use on the Tongass National Forest (Environmental Systems Research Institute 1985). Those alternatives were:

1. maintain existing data resources
2. provide improved manual databases, and
3. Provide automated databases.

An important benefit of maintaining existing data resources was that new costs would not be incurred. Also, the current data structure did respond, to varying degrees, to current tasks. However, large investments of time were needed to carry out even simple analytical procedures. Costs associated with these procedures would stay the same or most likely increase as the need for more comprehensive planning increased. There were also several procedural limitations associated with Alternative 1. Aggregation of mapping and tabular data to the Supervisor's Office, Regional Office, and Washington Office for reporting purposes was very difficult. Maps and associated tabular data were difficult to link for analysis purposes. There was also little correlation or integration of related resource boundaries (e.g., timber types and soils) in manual maps. This often led to problems in the preparation and analysis of interpretive maps and in the implementation of plans on the ground.

The second alternative would have used existing manual data to build a series of consistent base maps. A set of maps making up a manual database would have been produced. Design of maps and associated data tables would have been very similar to those developed in association with Alternative 3. Substantial costs would have been incurred for preparing the standardized manual maps and associated tabular data. Cost for updates would have been high too, although they would vary depending on frequency of update. Considerable cost would also have been associated with use of the manual system in planning activities, as in Alternative 1.

Alternative 3 involved the manual preparation of improved maps and associated tabular data, which were then automated for analysis and production use. In other words, it called for implementation of an automated GIS. The range of capabilities associated with such an automated system corresponded closely to the needs identified during implementation of the TLMP.

This alternative resulted in the highest initial costs for developing databases and loading data into the automated system (Figure 1). However, the cost of using a GIS for data analysis and presentation was much reduced from that of a manual system (Prather 1989). Time-consuming, labor-intensive, and duplicative efforts such as map redrafting, area calculations, and buffer generation are all performed automatically, resulting in a 2.5 benefit/cost ratio.

It was essential, however, that development of a new approach to data management and use be carefully planned to ensure its success (Antenucci 1987). Prior to selection and full-scale implementation of

a GIS on the Tongass National Forest, ESRI conducted a pilot test in 1985 on the Cleveland Peninsula in southern southeast Alaska, in association with an ongoing MAA. The pilot test was designed to examine and evaluate the proposed database design and to demonstrate and test the use of a GIS in a planning setting. The study area was composed of five VCU's on the Cleveland Peninsula. Eight map overlays of various natural resource information were incorporated into the system. Following successful completion of the pilot test, the Alaska Region requested approval from the Washington Office to acquire the ARC/INFO GIS to complete planning on Cleveland Peninsula. This request was approved. Based on those experiences, the Tongass National Forest was included in the National Controlled Evaluation of GIS as a pilot forest in 1987. This led to implementation and use of ARC/INFO GIS in the revision of the TLMP.

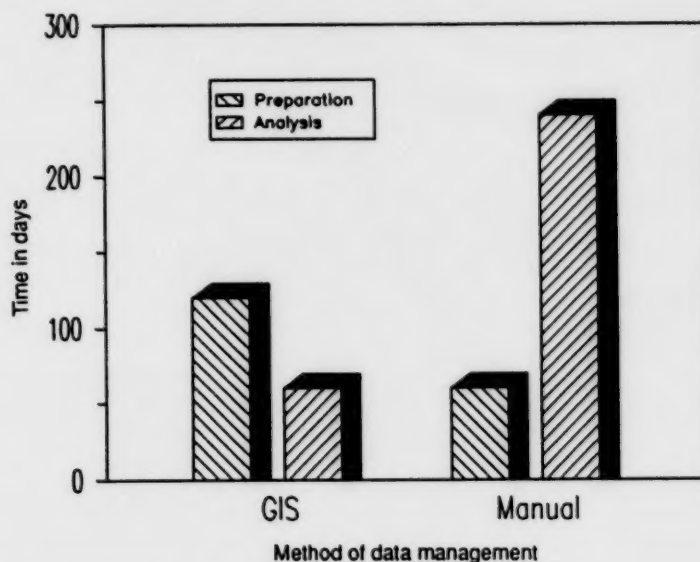


FIGURE 1. Comparison of time required for preparation of data and analysis for manual and automated information systems (from Prather 1989).

5.2 Implementation of GIS

Efficient data management is essential in the successful application of a GIS in natural resource planning (Johnston 1987). This was especially true in the Tongass National Forest, where the database is made up of approximately 2100 maps, making it one of the largest in the world incorporated into a GIS.

Thirty-nine kinds of data were identified as needed to manage the Tongass National Forest during the development of the regional database structure for GIS. A data dictionary was developed to describe individual variables and file formats associated with these 39 kinds of data (USDA Forest Service 1988b). All of this information was not needed in the process of TLMP revision. Computer resources may also have been severely affected if all of these resource layers had been included in the planning database. Of the 39 map layers, 11 were identified as needed for the revision effort (Table 3). Development and implementation of this GIS required the development of database management procedures that were unknown in the USDA Forest Service. A brief review follows that describes some of the problems encountered in establishing a GIS database of this magnitude and the solutions that were developed.

5.3 Management of Data in GIS

5.3.1 Silver polygons

One of the basic features and functions of a GIS is the ability to overlay two or more resource maps to develop a separate map incorporating the desired map information. This process was implemented in a effort to develop an individual response unit or polygon that would be used by all resources for inventory and analysis.

TABLE 3. Mapped information required for the revision of the Tongass Land Management Plan^a

Primary base series information for shoreline, administrative areas, and ownership
Vegetation
Roadless areas
Quadrangle map boundaries
Existing and planned roads
Value Comparison Units (1978 TLMP)
Elevation ranges derived from digital elevation model
Soil polygons
Stream channel type
Third-order watersheds
Recreation and visual polygons

^a DeGayner, E.J. GIS database design for the Tongass land management plan revision. USDA For. Serv., Tongass Natl. For., Juneau, Alaska. In prep.

The overlay process in a GIS often results in the formation of small polygons called sliver polygons. Sliver polygons have the potential to cause a severe impact on computer processing time because of the additional records that need to be handled. Slivers are often caused by: 1) lack of standard lines for stable features, such as shoreline, that occur on several maps; 2) differences in the location of polygon boundaries along ecological transition zones; and 3) legitimate subdivision of polygons. We will briefly discuss our experiences dealing with a specific case of the second cause, although the principles apply for the management of all sliver polygons.

Timber type and soil polygon boundaries are highly correlated on the Tongass National Forest. The same photography was used to create both, and vegetation characteristics were used to locate boundaries for both. When these two maps are overlayed, many sliver polygons are formed because the boundaries cross numerous times. A typical quadrangle map contains about 3000 timber type polygons and 2500 soil polygons. When these two covers are overlayed, a map containing approximately 15000 polygons is produced; 10000 of these are less than 0.5 ha. The maximum polygon density for efficient processing in the ARC/INFO system is from 3000 to 5000 polygons per quadrangle map. This problem must be addressed if data are to be managed efficiently.

A two-step process was used to solve this problem. The timber-type inventory has about 75 different descriptors for vegetation. The resource models that use timber-type information require only 16 of those descriptions. It was also possible to aggregate the nearly 600 soil mapping units to about 100 categories that were needed for planning purposes. Dissolving 75 timber type classes into 16 classes and 600 soil units into 100 had the effect of reducing the number of polygons by about 50%. The quality of the data needed for the analysis proposed was maintained throughout this process. However, new groupings of the original inventory data were not possible once polygon lines were dissolved.

The second step to solving the sliver polygon problem was to eliminate the slivers formed after maps were overlayed. Small polygons were merged with larger neighboring polygons. After timber type and soils maps underwent the dissolve process described previously and were overlayed, about 70% of the polygons were still less than 5 ha. However, these polygons represented an area of less than 5% of the total map. Therefore, if all polygons less than 5 ha were eliminated, processing requirements would be reduced by approximately 70%, while only 5% of the information on the map would be affected.

The effect of eliminating 0.5-, 2.0-, 4.0-, 8.0-, and 20.0-ha polygons on data integrity and efficiency was determined through a series of trial runs. Elimination of polygons of increasing size was performed on overlays of the timber type and soil maps for three quadrangles. If all polygons less than 4 ha were eliminated, a 40% reduction in number of polygons, computer storage space needed, and processing efficiency can be expected (Table 4). As the number of polygons decreased through elimination of larger and larger polygons, the average size of polygon increased, but the total area of the resource of interest stayed about the same (Figure 2).

TABLE 4. The effect of eliminating polygons on the number of remaining polygons per quadrangle map

Size of polygon eliminated (ha)	Number of polygons remaining
0.0	15000
0.5	6000
2.0	3600
4.0	2300
8.0	1500
20.0	900

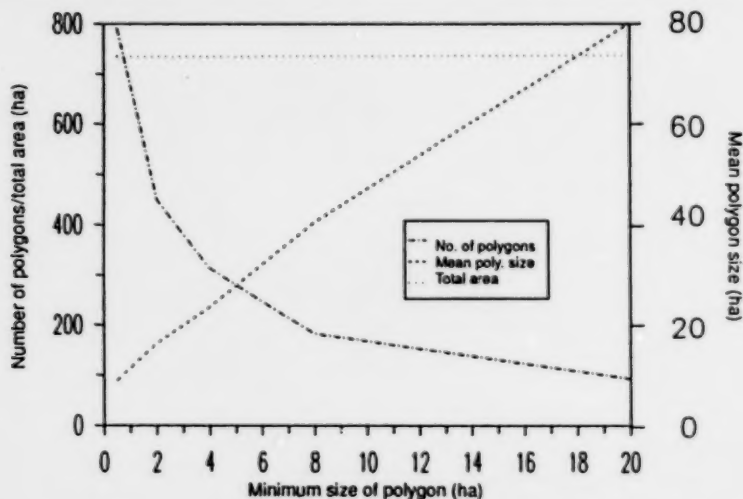


FIGURE 2. The effect of eliminating polygons ranging in size from 0.5 to 20 ha on average polygon size, number of polygons, and total area (from DeGayner, in prep.).

This approach facilitated the combination and conversion of mapped information to tabular information. The process resulted in little loss of the integrity of data associated with area parameters. However, the geographic information tends to be distorted as small polygons are combined and lose their integrity. As the polygon size eliminated increased, the percentage of the map that lost its original inventory classification increased (Figure 3). Also, small features such as buffers on riparian areas tend to be significantly reduced, unless the polygon elimination process is carefully applied.

5.3.2 Grid cells

Even with reduction of the number of polygons, substantial amounts of computer time were needed to implement inventory and analysis procedures on the Tongass National Forest database. An alternative approach to the traditional use of polygons with the GIS was implemented in the revision process to decrease the computer resources needed and to avoid spatial distortion.

A grid was electronically laid over each resource map. The attributes associated with the center point of the cell in the grid were then automatically assigned to the cell. The resulting cumulative grid cell information was processed very efficiently by the ARC/INFO GIS. The grid cell method of building a working database is processed 7 times faster than the polygon overlay method.¹ The process of assigning area and attribute values to a point from a polygon is rather simple and straightforward, and is not influenced by the complexity of the polygon map. Resource maps can be maintained in their original format and do not have to be simplified to be used.

¹ DeGayner, E.J. GIS database design for the Tongass land management plan revision. USDA For. Serv., Tongass Natl. For., Juneau, Alaska. In prep.

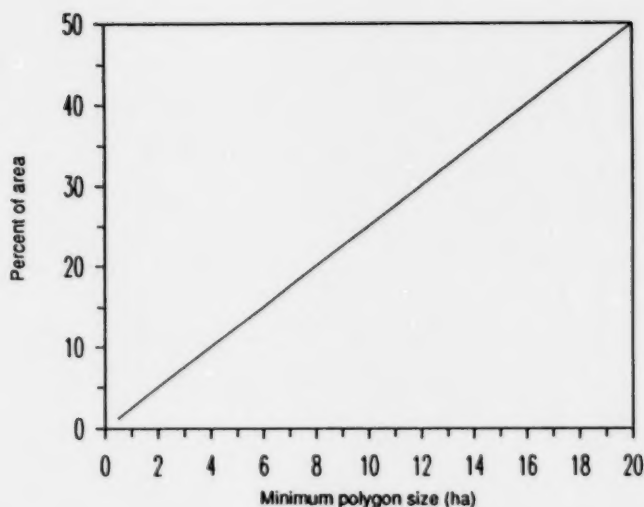


FIGURE 3. The effect of eliminating polygons ranging in size from 0.5 to 20 ha on proportion of inventoried area that is reclassified.

To determine the accuracy of area estimates associated with grid cells, six randomly generated 6-ha grids and five randomly generated 20-ha grids were applied to the timber-type map for three quadrangles. These applications generated area estimates for a number of attributes, including the 175-292 m³/ha timber volume class.² This process was repeated 120 times for the 6-ha grid and 100 times for the 20-ha grid. Total land area calculated from the grid cells was within 1% of that calculated from the polygon maps. The accuracy of estimates for particular attributes varied with size of the grid cells and the average size of the associated polygon. The standard deviations of the mean difference between area estimates from grid cells and polygon maps were 5% for the 6-ha grid and 7% for the 20-ha grid.

The grid cell approach appeared to adequately represent mapped resources on the forest to the level required by planning associated with revision of the TLMP. However, the structure of the grid cells is not conducive to creating and drawing base maps. More computer time is needed to create the maps from grid cells than with polygon files, and fine features — such as riparian areas — are not mapped as well. Therefore, the polygon files were used for developing planning maps whenever possible, while the grid cell information was used to generate and analyze tabular data.

The number of grid cells and computer storage space required increases exponentially as grid size decreases (Figures 4 and 5). One point per 6 ha would result in approximately 1.13 million points in the forest. One point per 20 ha would result in 338 000 points (the original TLMP had a 32-ha grid). A 6-ha grid would create a file requiring about 500 hours of computer time to build data files for analysis; a 20-ha grid would require 300 hours (Figure 6). An 8-ha grid was chosen to process revision data because it was considered to have sufficient resolution and reasonable processing time, and to be within hardware limitations.

5.4 Application of GIS

5.4.1 Wildlife

Once the inventory data files were established in the GIS, analysis of the data began in an effort to describe the resources in the forest and to evaluate the effects of proposed management alternatives on those resources. Thirteen wildlife species were selected as Management Indicator Species (MIS)

² Ibid.

to provide a basis for evaluation during the revision process (Table 5). Population changes of MIS are believed to reflect the effects of land management activities. The total number of species occurring within a planning area can be reduced through this concept to a number that promotes meaningful evaluation. The evaluation of the effects of management practices on MIS and their habitats provides an additional basis for ensuring the maintenance of biological diversity.

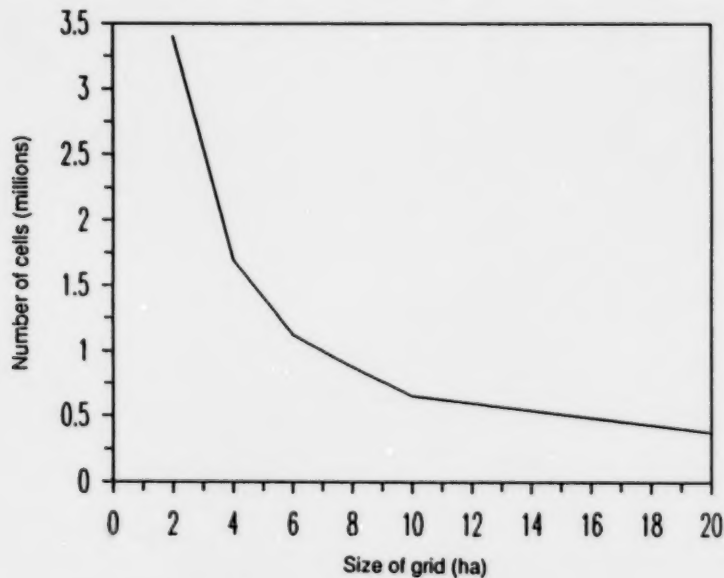


FIGURE 4. The effect of grid density on number of grid cells.

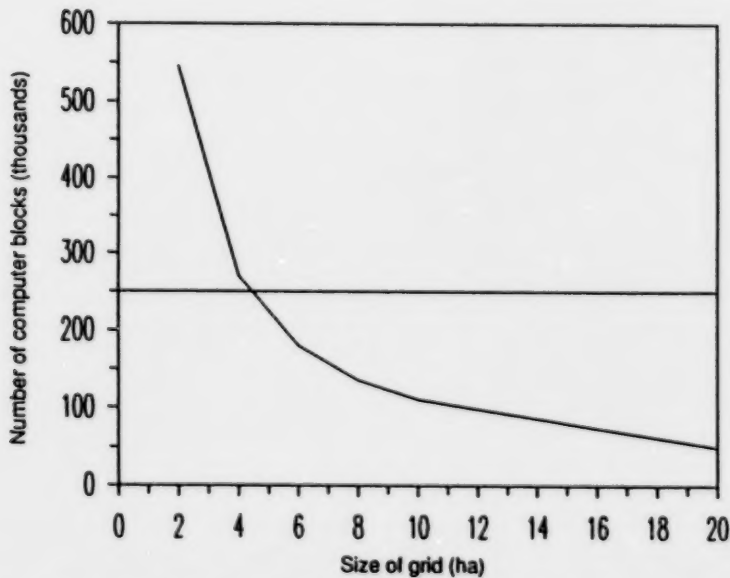


FIGURE 5. The effect of grid density on computer space required for storage. Horizontal line is upper limit of maximum computer file size.

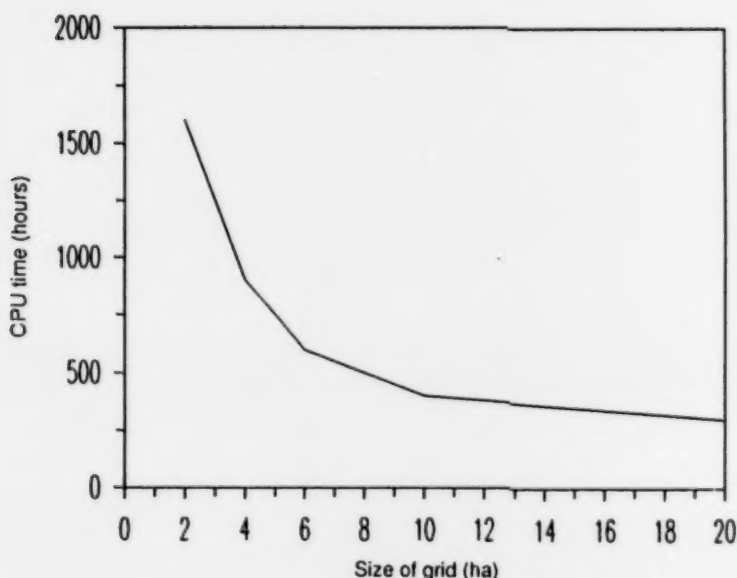


FIGURE 6. Computer processing required to develop data files for analysis purposes.

TABLE 5. Wildlife management indicator species being used in the revision of the Tongass Land Management Plan

Common name	Scientific name
Gray wolf	<i>Canis lupus</i>
Black bear	<i>Ursus americanus</i>
Brown bear	<i>Ursus arctos</i>
Marten	<i>Martes americana</i>
River otter	<i>Lutra canadensis</i>
Sitka black-tailed deer	<i>Odocoileus hemionus sitkensis</i>
Mountain goat	<i>Oreamnos americanus</i>
Red squirrel	<i>Tamiasciurus hudsonicus</i>
Vancouver Canada goose	<i>Branta canadensis fulva</i>
Bald eagle	<i>Haliaeetus leucocephalus</i>
Hairy woodpecker	<i>Picoides villosus</i>
Red-breasted sapsucker	<i>Sphyrapicus ruber</i>
Brown creeper	<i>Certhia americana</i>

A system was established to incorporate the MIS into the planning process (Figure 7). Inter-agency task groups developed habitat capability models for each of the MIS. Models were specifically designed for implementation on the GIS. These models required information on 10 habitat variables and other information (e.g., buffers) available from the GIS (Table 6). The models were verified by being run on portions of the Tongass National Forest where population data have been collected for the individual MIS or where task force members have personal knowledge of population levels. Estimates of habitat capability produced by the models were compared with available data or other estimates. This activity served as a verification procedure for both the models and habitat information in the GIS. Interactive revision of the models and the database will proceed as necessary.

By linking habitat capability models to the GIS, summaries may be generated for any combination of habitat variables, along with associated estimates of habitat capability for the species in question. A high degree of spatial resolution is possible for these habitat summaries and habitat capability estimates.

Step 1.

Evaluate species for proposed MIS



Step 2.

Select MIS for revision of
Tongass Land Management Plan



Step 3.

Develop habitat capability
models for MIS



Step 4.

Verification of MIS models



Step 5.

Application of MIS models in
planning and plan implementation



Step 6.

Continued development and
validation of MIS models



FIGURE 7. Process for incorporating management indicator species and associated habitat capability models into the planning process.

TABLE 6. Variables included in the GIS used to model habitat capability for the management indicator species for revision of the Tongass Land Management Plan

Management indicator species	Variables
Gray wolf	None (based on number of prey animals - black-tailed deer and mountain goat)
Black bear	Forest overstory type Upland Riparian Beach fringe Estuary Timber volume class Successional stage Stream class
Brown bear	Forest overstory type Upland Riparian Beach fringe Estuary Successional stage Stream class Disturbance/mortality
Marten	Forest overstory type Upland Beach fringe/riparian Timber volume class Successional stage Elevation
River otter	Forest Upland Riparian Beach fringe Timber volume class Successional stage Elevation Stream class Lake size
Sitka black-tailed deer	Forest overstory type Upland Riparian Timber volume class Successional stage Elevation Aspect Winter severity Predators Patch size
Mountain goat	Forest overstory type Timber volume class Successional stage Aspect Presence of cliffs
Red squirrel	Forest overstory type Successional stage
Vancouver Canada goose	Forest overstory type Beach fringe Riparian Timber volume class Successional stage Elevation
Bald eagle	Forest overstory type Upland Riparian Beach fringe Timber volume class Successional stage Elevation Stream class Lake size

TABLE 6. (Cont'd.)

Management indicator species	Variables
Hairy woodpecker	Forest overstory type Timber volume class Successional stage
Red-breasted sapsucker	Forest overstory type Timber volume class Successional stage
Brown creeper	Forest overstory type Timber volume class Successional stage

SITKA BLACK-TAILED DEER

The habitat capability model for Sitka black-tailed deer required information from: 1) the vegetation map layer (i.e., overstory tree species, forest productivity, and successional stage); 2) the stream channel type layer (i.e., riparian areas); 3) the soil layer (i.e., riparian areas); 4) the topographic map layer (i.e., aspect and elevation); and 5) the VCU layer (winter severity and presence of predators).³

Polygons of forested vegetation in the GIS database were assigned to: 1) timber volume classes ranging from forests without commercial value to high volume forests, depending on the average net volume of wood in the polygon; 2) one of five successional stages ranging from clearcut to old growth; and 3) one of eight forest types based on the dominant canopy tree species. These variables were used to represent the relationship between deer and vegetation in southeast Alaska. A preference has been demonstrated by deer during winter in this area for stands of old-growth western hemlock and Sitka spruce with high volumes of timber (Rose 1984; Schoen *et al.* 1985). Decreasing use by deer was noted in more open stands with lower timber volumes, and in clearcuts and second-growth forests.

Information on stream channel types and riparian soils in the GIS was used to describe and delineate riparian areas in southeast Alaska. The resulting information on location of riparian areas and information from the vegetation layer were used in the model to refine further the relationship between deer and their habitat in the model. Old-growth Sitka spruce riparian forests do not receive significant use by deer during the winter because forage production is limited and such forests tend to occur in cold-air drainages (Schoen *et al.* 1981).

A digital elevation model was used in conjunction with the GIS to assign each vegetation polygon to one of six aspect classes. This was useful in describing habitat for deer because slopes with southerly aspects are more valuable to deer in the fall, winter, and spring than slopes with northerly aspects (Hanley 1984). The digital elevation model was also used to assign one of six elevation classes to each vegetation polygon. Forested winter range at lower elevations is more valuable to deer than similar habitats at higher elevations where snow makes forage unavailable and movement difficult (Schoen and Kirchhoff 1985).

Winter severity in association with habitat conditions may have a significant influence on the health of a deer herd (Verme 1968). Annual snowfall was found to be the best indicator of winter severity in southeast Alaska as related to habitat capability for Sitka black-tailed deer (R. Flynn and M. Kirchhoff, Alaska Dep. Fish and Game, unpubl. data). The VCU's throughout southeast Alaska were rated in terms of four classes of typical winter severity as estimated by snow depth. The resulting map of winter severity in southeast Alaska was accessed through the GIS to provide this information to the model.

³ Suring, L.H. E.J. DeGayner, R.W. Flynn, M.D. Kirchhoff, J.W. Schoen, and L.C. Shea. 1992. Habitat capability model for Sitka black-tailed deer in southeast Alaska: winter habitat. USDA For. Serv., Alaska Reg., Juneau, Alaska. Draft document.

Predation can act as a significant controlling factor on deer populations (Keith 1974). This is especially true in those areas of southeast Alaska where gray wolves are present (Van Ballenberghe and Hanley 1984). The presence or absence of gray wolves in each of the 867 VCU's on the forest was determined and incorporated into the GIS database. We were then able to modify the habitat capability for deer by a predation factor wherever gray wolves occurred.

This habitat capability model was applied to the Kadashan Quadrangle in central southeast Alaska to provide an example of the information that may be generated (Table 7). These and other summaries provide the land manager with site-specific information on the amount, location, and quality of habitat available in a planning area and an estimate of the potential of that habitat to support wildlife populations. This information may be used to establish management objectives for wildlife and wildlife habitat. Similar information for other resources (e.g., timber, recreation, minerals) may be combined with the wildlife information to determine areas of potential conflict and tradeoffs associated with various management strategies.

TABLE 7. Application of the habitat capability model for Sitka black-tailed deer on the Kadashan Quadrangle in southeast Alaska (habitat and elevation examples)

Habitat/location	Area		Mean index	Habitat capability for deer		
	hectares	%		Total number	Number per ha	%
Old growth						
Low productivity	9238	19	0.18	811	0.09	26
Medium productivity	9084	19	0.31	1375	0.15	43
High productivity	2063	4	0.45	451	0.22	14
Unproductive forest and early to mid-succession	11366	24	0.10	542	0.05	17
Nonforest	16316	34	0.00	0	0.00	0
Total	48067	100	0.14	3179	0.07	100
Elevation						
Less than 245 m	20717	43	0.24	2414	0.12	76
245 m to 365 m	7572	16	0.14	529	0.07	17
365 m to 460 m	3462	7	0.14	236	0.07	7
Greater than 460 m	16316	34	0.00	0	0.00	0
Total	48067	100	0.14	3179	0.07	100

5.4.2 Land suitable for timber harvest

A model was also developed to estimate the amount of land in the forest that was tentatively suitable for timber harvest in response to provisions of the *National Forest Management Act* regulations (USDA Forest Service 1988c). Lands suitable for timber harvest constituted the land base in the planning process for determining the allowable sale quantity of timber and for planning all vegetation management practices associated with timber production.

Criteria included in the model, which defined biologically and administratively unsuitable lands, included: 1) land that is not forest land; 2) technology unavailable to ensure that timber harvest will not result in irreversible damage to productivity of soils or condition of watershed; 3) inadequate information to estimate responses of the land to timber management activities; 4) lack of reasonable assurance that adequate restocking will occur; and 5) land that has been administratively removed from timber production. The model was based on a stepwise process to evaluate National Forest lands (Figure 8). This model required information from four different inventories available through the GIS (Table 8). The 6.86 million ha of the forest were classified through the GIS to determine the land base available for potential timber production (Table 9). After proceeding through the six-step process, 1392598 ha were determined to be suitable for timber production (USDA Forest Service 1990).

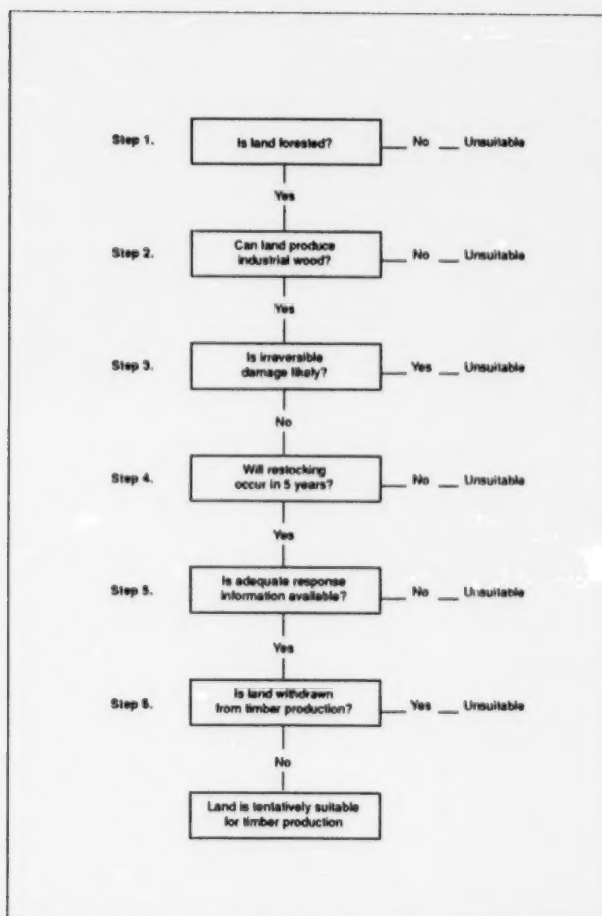


FIGURE 8. Process for identifying lands suitable for timber production in the Tongass National Forest of southeast Alaska.

TABLE 8. Inventories available in the GIS that were used to define lands tentatively suitable for timber production in the Tongass National Forest of southeast Alaska

Inventories	Criterion used
Forested land	Vegetation Soils Administrative Roads
Forested land capable of producing industrial wood	Vegetation
No irreversible damage	Soils
Restocking in 5 years	Soils
Vegetation response information	Vegetation Soils
Administratively available	Administrative boundaries

TABLE 9. Classification of lands suitable for timber production in the Tongass National Forest of southeast Alaska (from USDA Forest Service 1990)

Classification step	Area (ha)
Total National Forest area	6861834
Step 1. Is land forested?	
Fresh water	108314
Non-forest lands	2816138
Developed for purposes other than timber production	5848
	Remainder 3931534
Step 2. Can land produce industrial wood?	
Not capable of growing industrial wood products	19628
	Remainder 3911906
Step 3. Is irreversible damage to the landscape likely?	
Irreversible damage is likely to occur	344257
	Remainder 3567649
Step 4. Will restocking occur in 5 years?	
Regeneration will be difficult	39261
	Remainder 3528388
Step 5. Is adequate response information available?	
Response information is inadequate	1226160
	Remainder 2302228
Step 6. Is land withdrawn from timber production?	
Existing wilderness	895432
Existing Research Natural Areas	8464
Existing Experimental Forest	5734
Lands tentatively suitable for timber production	1392598

6 CONCLUSIONS

The development and verification of the GIS database, and the resource models associated with it, have provided users with unprecedented access to the resource inventories available for the Tongass National Forest. The ability to describe wildlife habitat and timber resources for a particular analysis area (forest-wide planning) or site (plan implementation) was greatly enhanced because numerous vegetation and landscape attributes may be used to describe that area or site. Areas where the potential exists for resource conflict can be graphically illustrated for numerous management alternatives. Such maps, along with tabular summaries of information, provide the resource manager and the public with a clearer understanding of management benefits and consequences. The design and structure of the database being used in the revision of the TLMP, and the availability of a GIS, will result in a more implementable plan than was produced originally. Access to the database and the analysis techniques is greatly enhanced and will allow validation to be incorporated into implementation of the plan.

It is anticipated that the GIS database and associated resource models will be made readily available to users through menu-driven systems. This will vastly increase our ability to access inventory information and will improve the quality of our analyses. However, the job of the resource specialist in management planning and implementation will not necessarily be made easier because of the presence of a GIS. The increasing complexity of the issues associated with managing National Forests will require increasingly complex analyses. The resource specialist will need to have a complete understanding of the strengths and weaknesses of the inventories being used. The specialists will have to understand the functions and assumptions incorporated into the models being used so that the models are applied properly. Additional analysis techniques will need to be developed because menu systems cannot anticipate all the "what ifs" that may arise in the planning process. The biologist or forester will need to know the limitations of the software and hardware being used, to ensure analyses and inquiries will be successful.

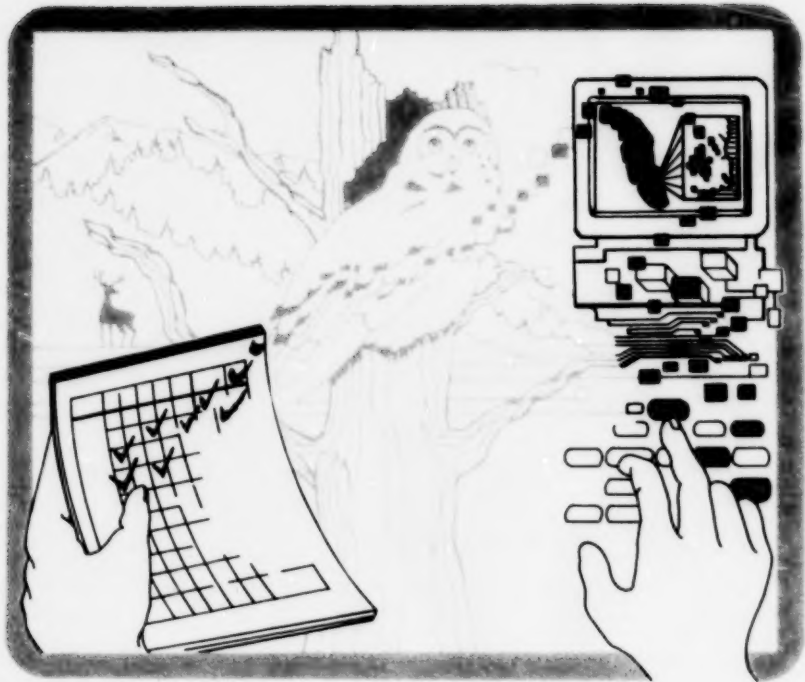
The experiences of the Tongass National Forest in the design and implementation of a GIS have lessons for others considering the use of a GIS in management of forest resources. Other than in size, the Tongass National Forest is not unique in its use of a GIS. Other management areas may be smaller in area, but they often have more complex inventories, more management options, and more variable landscapes. It is important not to expect too much from a GIS. Our ability to use and present information from resource inventories is greatly enhanced through the use of a GIS. However, the size of our database and associated software and hardware limitations restricted our ability to use the full capability of the GIS. Design and implementation must be approached cautiously and be done thoroughly to ensure that the system will do what is needed and expected.

LITERATURE CITED

- Antenucci, J.C. 1987. Overview of GIS implementation and applications in resource management and land cadastre agencies. *In Proc. Int. Conf. and Workshop on Land and Resource Evaluation for National Planning in the Tropics*. USDA For. Serv., Gen. Tech. Rep. WO 39, pp. 363-369.
- Environmental Systems Research Institute. 1984. User needs and data requirements report, Tongass National Forest (Ketchikan and Stikine areas). Natural Resource Management Information Study (USDA For. Serv. Contract 53-0109-4-00161), Redlands, Cal.
- . 1985. Final design report and implementation plan, Tongass National Forest (Ketchikan and Stikine areas). Natural Resource Management Information Study (USDA For. Serv. Contract 53-0109-00161), Redlands, Cal.
- Hanley, T.A. 1984. Relationships between Sitka black-tailed deer and their habitat. USDA For. Serv., Gen. Tech. Rep. PNW-168.
- Hughes, J.H. 1985. Characteristics of standing dead trees in old-growth forest on Admiralty Island, Alaska. M.S. thesis. Wash. State Univ., Pullman, Wash.
- Johnston, K.M. 1987. National resource modeling in the geographic information system environment. *Photogrammetric Engineering and Remote Sensing* 53:1411-1415.
- Keith, L.B. 1974. Some features of population dynamics in mammals. *Proc. Int. Congr. Game Biol.* 11:17-58.
- Lebeda, C.S. and J.T. Ratti. 1983. Reproductive biology of Vancouver Canada geese on Admiralty Island, Alaska. *J. Wildl. Manage.* 47:297-305.
- Peek, J.M., M.R. Pelton, H.D. Picton, J.W. Schoen, and P. Zager. 1987. Grizzly bear conservation and management: a review. *Wildl. Soc. Bull.* 15:160-169.
- Prather, M.L. 1989. The Tongass National Forest geographic information system (GIS) experience. *In Proc. Seminar on the Geographic Information Systems Awareness*. D. Winn, R.E. Beverly, and G.W. Moore (editors). USDA For. Serv., Intermount. Reg., Ogden, Utah, pp. 61-66.
- Rose, C.L. 1984. Response of deer to forest succession on Annette Island, southeastern Alaska. *In Proc. Symp. Fish and Wildlife Relationships in Old-Growth Forests*. W.R. Mehan, T.R. Merrell, Jr., and T.A. Hanley (editors). Amer. Inst. Fish. Res. Biol., Reintjes Publ., Morehead City, N.C., pp. 285-290.
- Schoen, J.W. and M.D. Kirchhoff. 1985. Seasonal distribution and home-range patterns of Sitka black-tailed deer on Admiralty Island, southeast Alaska. *J. Wildl. Manage.* 49:96-103.
- Schoen, J.W., M.D. Kirchhoff, and J.H. Hughes. 1988. Wildlife and old-growth forests in southeastern Alaska. *Nat. Areas J.* 8:138-145.
- Schoen, J.W., M.D. Kirchhoff, and M.H. Thomas. 1985. Seasonal distribution and habitat use by Sitka black-tailed deer in southeastern Alaska. Final Rep. Fed. Aid in Wildl. Rest., Alaska Dep. Fish and Game, Juneau, Alaska. Proj. W-17-11, W-21-1,2,3, and 4. Job 2.6R.
- Schoen, J.W., M.D. Kirchhoff, and O.C. Wallmo. 1981. Seasonal distribution and habitat use by Sitka black-tailed deer in southeastern Alaska. Vol. II. Fed. Aid in Wildl. Rest., Alaska Dep. Fish and Game, Juneau, Alaska. Proj. W-22-1, Job 2.6R.
- . 1984. Sitka black-tailed deer/old-growth relationships in southeast Alaska: implications for management. *In Proc. Symp. on Fish and Wildlife Relationships in Old-Growth Forests*. W.R. Mehan, T.R. Merrell, Jr., and T.A. Hanley (editors). Amer. Inst. Fish. Res. Biol., Reintjes Publ., Morehead City, N.C., pp. 315-319.
- Sidele, W.S. and L.H. Suring. 1986. Management indicator species for the National Forest lands in Alaska. USDA For. Serv., Alaska Reg., Tech. Publ. R10-TP-2.

- Sidle, W.S., L.H. Suring, and J.I. Hodges, Jr. 1986. The bald eagle in southeast Alaska. USDA For. Serv., Alaska Manage. Bull. R10-MB-9.
- USDA Forest Service. 1978a. Landtype/timber task force working report. Alaska Reg., Juneau, Alaska. TLMP-3.
- . 1978b. Wildlife task force working report. Alaska Reg., Juneau, Alaska. TLMP-6.
- . 1979. Tongass land management plan final environmental impact statement, part 1. Alaska Reg., Juneau, Alaska. Ser. R10-57.
- . 1984. Tongass land management plan evaluation report. Alaska Reg., Juneau, Alaska. Admin. Doc. 139.
- . 1988a. Status of the Tongass National Forest 1987 report. Alaska Reg., Juneau, Alaska. Manage. Bull. 35.
- . 1988b. Tongass National Forest geographic information system data dictionary. Alaska Reg., Juneau, Alaska.
- . 1988c. Tongass Land Management Plan: criteria for determining the tentatively suitable forest land classification. Alaska Reg., Juneau, Alaska.
- . 1989. Issues for the Tongass National Forest land and resource management plan revision. Tongass Natl. For., Juneau, Alaska.
- . 1990. Analysis of the management situation. Tongass National Forest land and resource management plan revision. Appendix, Vol. II. Tongass Natl. For., Juneau, Alaska. Manage. Bull. R10-MB-91.
- Van Ballenberghe, V. and T.A. Hanley. 1984. Predation on deer in relation to old-growth forest management in southeastern Alaska. *In* Proc. Symp. on Fish and Wildlife Relationships in Old-Growth Forests. W.R. Mehan, T.R. Merrell, Jr., and T.A. Hanley (editors). Amer. Inst. Fish. Res. Biol., Reintjes Publ., Morehead City, N.C., pp. 291–296.
- Verme, L.J. 1968. An index of winter weather severity for northern deer. *J. Wildl. Manage.* 32:566–574.

6



Putting Data, Experience and Professional Judgment to Work in Making Land Management Decisions

Bruce G. Marcot
Wildlife Ecologist
USDA Forest Service
319 S.W. Pine Street
P.O. Box 3890
Portland, Oregon

ABSTRACT

Biological evaluations and resource decision-making entail use of administrative procedures, quantitative scientific data, and expert knowledge. Four kinds of information are needed to make good management decisions: scientific data, ecological theory, professional judgment, and personal experience. Each kind of information is unique in its utility for legal, scientific, and administrative settings. Scientific uncertainty can be evaluated with risk analysis techniques and used in guiding resource management decisions with decision theory techniques. Monitoring the application, results, and underlying assumptions of management guidelines are ways to decrease uncertainty, particularly if the monitoring is conducted in an adaptive management framework. A useful adaptive management approach requires measurable parameters, a scientifically sound study design, management trigger points, availability of management options, and willingness to change.

Several examples of analyzing risk and using decision theory are illustrated in this paper, including methods of expected value of perfect information and expected value of sample information, decision tree analysis, and use of expert systems. A hypothetical case study of managing down wood for a mycophagous small mammal guild is presented to illustrate the use of various kinds of information and the application of monitoring and adaptive management.

ACKNOWLEDGMENTS

This paper derives from a presentation at the joint British Columbia-USDA Forest Service workshop on "Integrating Timber and Wildlife in Forest Landscapes: A Matter of Scale," held during October 16-20 1989, at Pack Experimental Forest, Eatonville, Washington, USA. I thank the attendees of the workshop for their helpful critique of the presentation and constructive suggestions for improving the paper. The paper benefits also from additional discussions with Marvin Eng, Richard Holthausen, and Scott McNay.

TABLE OF CONTENTS

ABSTRACT	140
ACKNOWLEDGMENTS	141
1 INTRODUCTION	143
2 USE OF INFORMATION IN WILDLIFE EVALUATIONS	143
2.1 Kinds of Information Used in Biological Evaluations	143
2.2 Characteristics of Information	144
3 HANDLING UNCERTAINTY IN RESOURCE ASSESSMENTS AND DECISION-MAKING	145
3.1 Risk Analysis and Risk Management	145
3.2 Monitoring	145
3.3 Adaptive Management	147
3.4 Analyzing Risk and Using Decision Theory: Examples	148
3.5 Modeling Resource Effects and Expert Systems	150
3.6 Where Can Information Go Wrong?	153
4 COMBINING DATA, EXPERIENCE, AND PROFESSIONAL JUDGMENT: A CASE STUDY	154
4.1 The Case Study: Providing Habitat for Mycophagous Mammals	154
4.2 What is at Risk?	154
4.3 Guidelines for Maintaining the Mycophagous Guild	155
4.4 Key Assumptions	156
4.5 Questions to Address	156
5 SUMMARY AND CONCLUSIONS	157
LITERATURE CITED	158

FIGURES

1 A simple risk analysis model to help prioritize monitoring activities	147
---	-----

TABLES

1 Kinds of information used in making land management evaluations and decisions	144
2 Kinds of tasks suitable for expert systems in land management evaluations and decisions	151
3 Mycophagous (hypogeous fungus-eating) small mammals (Rodentia) of the Pacific Northwest	154

1 INTRODUCTION

The art of wildlife management is a unique marriage of scientific method and intuition. The science portion of the marriage provides a theoretical basis and quantitative data for managing populations and habitats. The intuition portion fills in the blanks when scientific knowledge is unavailable, and consists of mostly unarticulated expertise. When developing management guidelines, most wildlife managers and applied researchers use intuitive knowledge above and beyond their explicit scientific knowledge. This paper addresses how data, experience, and professional judgment are combined in environmental assessments and resource planning decisions.

The objectives of this paper are to explore: 1) concepts related to using information from a variety of sources and levels of precision; 2) appropriate uses of incomplete information; 3) ways of dealing with uncertainties in assessments and decisions; and 4) ways of constructing advisory models from various sources of information. Much of this paper refers to management of wildlife habitats on public, multiple-use lands (such as in U.S. National Forests), but the concepts are applicable to any land base where management decisions entail uncertainties.

2 USE OF INFORMATION IN WILDLIFE EVALUATIONS

Many kinds of information are typically brought to bear when environmental assessments are being conducted and management guidelines developed. Statistically accurate data gathered on-site or in similar environmental contexts are of high value, but such site-specific data are not always available. Thus, personal expertise is commonly part of the tool kit as well.

An example is the USDA Forest Service biological evaluation for project assessment (a similar methodology can be used by the B.C. Ministry of Forests). A biological evaluation as conducted by wildlife biologists on National Forests in the U.S. is a procedure for assessing what degree of impact proposed forest management activities will have on specific wildlife habitats or populations, and for identifying ameliorative or mitigative actions. For instance, a biological evaluation can be used to assess how a proposed timber harvest might affect desired habitat conditions of mature and old-growth forests for pileated woodpeckers (*Dendrocopos pileatus*) in a specific set of forest stands.

2.1 Kinds of Information Used in Biological Evaluations

The information used in biological evaluations can be classified as administrative, quantitative, and expert. **Administrative information** consists of explicit wildlife objectives in terms of kinds, amounts, and distributions of habitats necessary for managing the species of interest. This defines desired habitat conditions. Administrative objectives may or may not be based solely on scientific data. Amounts of habitat allocated for a species objective, for example, may be compromised by competing uses for the same forest land.

Quantitative information in a biological evaluation consists of scientific data on wildlife-habitat relationships. Quantitative information might consist of scientifically collected facts, as well as more general ecological theory. An example is the amount of mature and old-growth forest occurring within an annual home range of a breeding pair of pileated woodpeckers. Other quantitative information might include inventory data on forest habitats and models of tree growth and timber yield.

Finally, **expert knowledge** is used to synthesize inventories, projection models, and other quantitative information to compare conditions in the project against conditions currently existing or desired. Expert knowledge often extends what we know quantitatively about how projects affect environments by applying tacit rules that identify when particular effects of a project are important. For instance, a particular timber sale may not significantly affect quality of pileated woodpecker habitat if the project entails small group selection, occurs in less wind-prone areas, is timed outside the breeding season, and is not placed close to

key nesting or feeding stands. Expert rules of this type are not inherently contained in inventory information, in scientific data on the species, nor in quantitative models of forest stand development and wildlife-habitat relationships. Rather, they are derived from professional judgment, personal experience, and an understanding of the species' ecology and site-specific properties of the location of the project. Expert rules can be assembled, shared, stated explicitly in documenting decisions and management guidelines, and even tested.

2.2 Characteristics of information

What are the characteristics of various kinds of information used in making land management evaluations and decisions? **Scientific data** are derived from direct field observations and are thus applicable to specific circumstances (Table 1). As well, scientific data are collected in a repeatable manner, although such studies are often not duplicated over large areas. They are statistically reliable, and those presented in publications are reviewed by peers. Scientific knowledge in the field of wildlife management is best gathered by hypothesis-testing (Romesburg 1981) through the use of the "hypothetico-deductive process."

TABLE 1. Kinds of information used in making land management evaluations and decisions

Category	Characteristics
Scientific data	Direct field observations (specifically applicable) Scientifically collected (repeatable) Statistically accurate (reliable) Peer reviewed (credible)
Ecological theory	Conceptual (generally applicable) Global (based on principles) Peer reviewed (credible)
Professional judgment	Expert knowledge (credible) Deep understanding of relationships Heuristic (deals with uncertainties) Legally admissible
Personal experience	Anecdotal (contextual, not repeatable) Diverse (useful, eclectic, synthetic)

Ecological theory, on the other hand, is mostly conceptual. Its application to particular contexts is general rather than specific. Theories are global principles induced from site-specific information or extrapolated from mathematical treatment of concepts. In publications, ecological theory is reviewed by peers and accepted, to varying degrees, by the scientific community. Ecological theory is robust, not site-specific, and applies on a broader scale than empirical scientific data.

Professional judgment consists of an expert understanding of resource consequences. It is a deep comprehension of concepts, ecological theory, and environmental effects, as well as knowledge of local conditions. As heuristic knowledge, professional judgment enables the expert to make educated guesses when necessary, to recognize promising approaches to solving problems, and to deal effectively with errors and uncertain or incomplete data. Professional judgment also is legally admissible in U.S. courts as a source of knowledge and understanding, as any expert witness can testify. Professional judgment can be subjective and biased according to one's experience and training.

Finally, **personal experience** differs from scientific data in being based on anecdotal observations. Thus, personal experience may not be repeatable and is often unarticulated (Polanyi 1962). Personal experience, along with scientific data and theory, forms the foundation for professional judgment, although it varies greatly among individuals. Personal experience is not subject to a repeatable, statistical framework or to peer review. It is a diverse and eclectic bank of knowledge, subject to individual biases and predilections, but it still may yield reliable and useful information. In legal settings, however, it is often subject to debate.

How useful are each of these sources of knowledge in various arenas of forest resource management? Collectively, scientific data and ecological theory are most useful in legal and scientific settings, but generally must be interpreted through development and technology transfer programs for use in administration and on-the-ground resource management. On the other hand, professional judgment and personal experience best fit the kinds of information needed for management, although they are of limited utility in scientific circles (e.g., for including in publications or helping advance scientific knowledge) and legal settings, unless they constitute the sole pertinent information available and are well documented with field notes, affidavits, and depositions.

All four kinds of information — scientific data, ecological theory, professional judgment, and personal experience — are needed for making decisions for resource planning. However, any of these sources of information can be fraught with uncertainties. One must be aware of the limitations and risks of using each kind of information in environmental evaluations and resource management decision-making. For example, "soft data" — such as those afforded by personal experience and professional judgment — allow for quick decisions but can be heavily biased. Such information should be independently evaluated or monitored, or applied first on a case study or pilot project. When soft data are used, peer review and public participation in decision-making are paramount. The next section explores ways to make uncertainties more explicit by using various evaluation techniques.

3 HANDLING UNCERTAINTY IN RESOURCE ASSESSMENTS AND DECISION-MAKING

Much of resource evaluation and decision-making deals with uncertainty. It is the hallmark of scientists, but the lament of decision-makers, to qualify conclusions with uncertainties.

3.1 Risk Analysis and Risk Management

Scientists can estimate scientific uncertainty by using **risk analysis**. Forms of scientific uncertainty include variability in the biological system, errors of estimation, invalid prediction models, and ambiguous or inappropriate questions (Marcot 1986a).

These sources of uncertainty are but part of what needs to be considered when one is making resource management decisions. Scientific uncertainty might increase risk in decision-making. Evaluating and weighing the costs and potential outcomes of acting in the face of uncertainties is the business of **risk management**. Risk management is conducted by decision-makers, managers, line officers, politicians, and courts, and ultimately the public in the form of electing governmental representatives, voting on resource management issues, and participating in the natural resource planning process. Evaluating risk in natural resource management is the domain of decision theory.

In the U.S., the *National Environmental Policy Act* (1976) mandates the prediction, evaluation, and documentation of environmental impacts caused by any activity potentially affecting natural conditions. Recently, regulations from the U.S. Council on Environmental Quality have called for resource persons to acknowledge unavailable information, disclose areas of significant uncertainty, state if and at what cost such information can be gathered, and evaluate the relevance of the unavailable information. The regulations also call for impacts from projects to be evaluated using theoretical approaches or research methods generally accepted in the scientific community. The purpose of the regulations is to encourage scientific risk analysis, results of which can then be used in risk management. It is expected that this process better informs decision-makers and the public of the risks and costs associated with a project.

3.2 Monitoring

One method of dealing with uncertainty is through monitoring, as mandated by the regulations pursuant to U.S. *National Forest Management Act* of 1976 (36 CFR 219). Monitoring entails tracking key biological

parameters and validating crucial assumptions. Monitoring is one vital part of the adaptive management process (Walters and Hilborne 1976; Marcot *et al.* 1986; Walters 1986).

Three basic kinds of monitoring can help track implementation, effectiveness, and validity of management guidelines. **Implementation monitoring**, or compliance monitoring, refers to verifying that the management guidelines are indeed carried out on the ground in the time and procedure stipulated. For example, are the requisite numbers of hard snags and replacement green trees actually left on site after a timber harvest? **Effectiveness monitoring** refers to testing whether the biological system responds as anticipated. For example, do primary and secondary cavity-nesting birds and mammals actually use the snags provided? **Validation monitoring** refers to assessing the veracity of underlying assumptions used to generate the guidelines in the first place. For example, is the assumed relationship between snag density and woodpecker population density really linear and sloped according to expectations? Much of the following discussion refers to effectiveness and validation monitoring.

A monitoring program can help the manager deal with uncertainty by providing basic, empirical information. Inventory and monitoring information, along with research results, can be used to model effects of project implementation. Modeling helps us to articulate what we think we understand about the system and guides us in identifying key unknowns and assumptions (Bunnell 1989). In the modeling process, sensitivity analysis is useful for identifying potential effects of uncertain parameters, and for prioritizing parameters for further study or monitoring.

Monitoring is useful for testing the anticipated effects on biological systems of implementing management standards and guidelines. In this framework, the timing of implementing the standards and guidelines, as well as the time frame over which the biological system should respond, must be clearly identified. Although effects of short-term elimination or changes in habitats and environments are often readily apparent, some biological responses to less drastic measures are not always immediate.

To monitor effects of guidelines, it is of course essential to have a clear understanding of what those guidelines are. They should be complete, biologically sound, credible, practical, and clearly written and understandable by managers and the public alike. Where possible, they should be derived from an appropriate mix of scientific research, ecological theory, professional judgment, and, in some cases, personal experience. To aid decision makers in assessing guideline effects on resource conditions, trade-offs as a result of implementing the guidelines should be clear. Furthermore, the guidelines themselves should be no more complex than necessary to be effective, and — perhaps most importantly — should be clearly linked to quantifiable management objectives.

To monitor guidelines properly, a monitoring implementation plan should be written, reviewed, and officially sanctioned. The plan should describe standards for data collection and analysis. It should also specify goals, objectives, funding, and indicators of implementation success. Such indicators should entail identifying an acceptable range of reliability and standards for including subjective (but not arbitrary!) evaluation of results.

What, specifically, should be monitored? A simple risk analysis might help prioritize budgets and guide levels of confidence needed in monitoring programs. The risk analysis might set up a two-by-two matrix listing risk of error across the top and risk of loss down the side (Figure 1). Risk of error refers to the likelihood that implementing a particular management guideline will fail to result in anticipated biological responses. Risk of loss refers to environmental results such a failure occur.

An example is the implementation of management guidelines intended to provide down wood habitat for wildlife (see below for further explanation of this scenario). The risk of error is the likelihood that providing down wood at particular densities, amounts, and distributions would not meet the population objectives stated for the associated wildlife species. Ideally, to assess this risk of error, one would use local scientific data, for example, from a regression model that predicts wildlife population abundance given down wood attributes and abundance. Where such data are lacking, the next resort is to use ecological theory, including results of empirical studies on other, related species or habitats, or theory on down wood amounts and distributions needed to provide for the foraging and cover needs for each species. Where theory or other studies are lacking, professional judgment and personal experience can help provide guidelines, although these constitute much "softer data" and likely carry a much higher risk of error.

		Risk of error	
		low	high
Risk of loss	low		
	high		

FIGURE 1. A simple risk analysis model to help prioritize monitoring activities. Risk of error refers to likelihood that implementing a particular management guideline will fail to result in anticipated biological responses. Risk of loss refers to environmental results should such a failure occur. See text for explanation and an example.

In this example, risk of loss refers to implications of declines or losses of wildlife associated with down wood. It could also include increases in risk of fire incidence, intensity, and spread in unburned down wood (fuels) as a basis for trade-off analyses.

When both risk of error and risk of loss are high, effectiveness monitoring and validation monitoring studies become imperative. Other combinations of risk of error and risk of loss carry lesser priorities, depending on the situation, and monitoring programs can be guided accordingly. Obviously, if the wildlife species involved is threatened or endangered, risk of loss is always high. More subtly, however, if the species plays a key function in the ecosystem, such as being an important pollinating or dispersal vector for maintaining forest health, risk of loss can also be high even if the species is not threatened or endangered. Again, evaluating such outcomes demands clearly stated objectives and assumptions for the management guidelines.

Over time, such a risk assessment can be updated from experience and new data. Because risk attitudes tend to change with time and circumstances, it may be useful to monitor shifts in public and managerial opinions. When monitoring information is used in the broadest sense to realign guidelines, this process becomes adaptive management.

3.3 Adaptive Management

The adaptive management process views a management decision as a hypothesis. The hypothesis consists of the key assumptions underlying a management guideline. To test the key assumptions, relevant biological variables are monitored in the field and management guidelines adjusted if the biological system responds less favorably than expected. The foundation of management guidelines is often a combination of scientific information and professional and personal knowledge. Thus, testing key assumptions of management guidelines amounts to evaluating the validity of expert rules derived from professional judgment.

Four factors are necessary for the adaptive management mechanism to work correctly. First, **clear and measurable parameters must be identified** that represent the assumptions being tested. A feasible method for estimating the values of those parameters must also exist. For example, when monitoring the efficacy of established pileated woodpecker habitats, one must have a reliable protocol for inventorying the presence of breeding pairs of birds. Second, **clear evaluation criteria must be written** that would trigger reevaluation of management direction. For example, locations of habitats allocated for pairs of woodpeckers might be changed if monitoring revealed a lack of occupancy for three consecutive breeding seasons. Third, **options must be available** for altering management direction. For example, monitoring home range characteristics of pileated woodpeckers with the intent of setting habitat sizes according to amounts of mature and old-growth forest used per pair is fruitless if such habitat is unavailable for

reallocation. A combination of scientific data, such as field methods and habitat inventories, and professional experience can provide the basis for appropriate application of the adaptive management process. And fourth, **management must be willing to change** if monitoring experience suggests that change is needed.

No monitoring and adaptive management program should be started without each of these four conditions first being evaluated. Nothing replaces measurable parameters, a scientifically sound study design, management trigger points, availability of management options, and willingness to change. Monitoring programs lacking any of these components simply waste time, money, and talent.

Ways of modeling environmental effects in light of uncertain or incomplete information include risk analysis and related approaches. Two examples are estimating the expected value of information and developing decision trees. Also, computer programs known as expert systems are a means of articulating professional judgment. These tools are useful in an adaptive management framework. The next sections discuss these approaches.

3.4 Analyzing Risk and Using Decision Theory: Examples

Risk assessment and decision theory refer to a suite of tools for depicting, estimating, and evaluating implications of uncertain information in decision-making (Hillier and Lieberman 1980). Such approaches make uncertainties and assumptions explicit for monitoring and testing. They are also useful for identifying risk attitudes of managers, as with the use of utility theory. Finally, they aid decision-making by accounting for uncertain outcomes, as with the use of decision tree analysis.

Incomplete information can be dealt with in a variety of ways. The examples that follow illustrate how risk assessments and decision theory approaches can be used for project assessment in the presence of incomplete information.

Expected value of perfect information. From decision theory, one approach is to evaluate the expected value of perfect information (EVPI) by estimating the expected loss with available estimates of conditions. That loss becomes the maximum amount we would pay to eliminate risk completely.

For example, with available habitat inventories and habitat relationships models, we might estimate that one-third of habitat capability for reproductive pairs of pileated woodpeckers might be incurred with a particular timber sale in a specific basin. Such an estimate, let us say, would be made from our professional judgment based on incomplete information on the species' local distribution and our general knowledge of its response to changes in habitat conditions. The value of the amount of habitat lost then becomes the amount we would pay (EVPI) to get perfect information on the species' local distribution and the response of the population to the project in question. For instance, the value of pileated woodpecker habitat affected by, and possibly lost to, a timber sale may be \$4 million (undiscounted stumpage value). Thus, using EVPI, we would find it valuable to spend up to, but no more than, \$4 million to gain perfect information on the response by pileated woodpeckers to that project.

Typically in this approach, uncertainty of our understanding can be thought of as variability in response of the species. Uncertainty is modeled as variance (standard deviation) of the response. For example, initial inventories of pileated woodpeckers might result in an estimate of the average crude density of breeding pairs and some sample standard deviation around that average. The greater our uncertainty of habitat capability, the greater the range of possible responses, expressed as the expected response plus or minus the standard deviation of population response. Thus, with great uncertainty, the cost of additional information on impacts to the pileated woodpecker population could be very small — or very great.

Expected value of sample information. A related approach entails estimating the expected value of sample information (EVSI). In this approach, the value of incremental additions to knowledge is evaluated with respect to how well it narrows the standard deviation of predicting outcomes.

Following the above example, using existing, imperfect information, we might project a 30% local decline in habitat capability for pileated woodpeckers with a standard deviation of 40% of the expected value. Let us say that before the project, the habitat is estimated to be capable of supporting 10 reproductive pairs of pileated woodpeckers, with a standard deviation of 40% of the expected value. Let us say that

before the project, the habitat is estimated to be capable of supporting 10 reproductive pairs of pileated woodpeckers, with a standard deviation of $\pm 40\%$ of 10 (thus, 10 ± 4 pairs, or from 6 to 14 pairs). The timber sale project would reduce that capability by 30%, to 7 ± 2.8 pairs ($2.8 = 40\%$ of 7), or from 4.2 to 11.8 pairs.

Let us also say that our original planning objectives dictate that habitat capability for no fewer than six pileated woodpecker pairs be maintained in the area. Six pairs becomes our "breakeven" point, below which we incur a cost of creating new habitat. This cost of new habitat is called the "unit loss," and in this case represents the value of standing timber needed as habitat for one pair of pileated woodpeckers. The (undiscounted) unit cost can be estimated as the area needed per pair times the value per acre. Let us say that, by administrative objective, 300 acres are required per pair of woodpeckers and that the current undiscounted stumpage value of mature and old-growth timber averages \$50 000 per acre. Thus, the unit cost of maintaining a pair of pileated woodpeckers is \$15 million (300 acres needed per pair $\times$ \$50 000 per acre). This is the mitigation cost per pair of woodpeckers of reducing habitat capability below the objective six pairs.

At this stage, we can calculate the expected loss of providing pileated woodpecker habitat (procedure follows Levin and Kirkpatrick 1975). First, calculate the number of standard deviations between the current mean habitat capability and the break even point:

$$\frac{10 \text{ pairs} - 6 \text{ pairs}}{4 \text{ pairs S.D.}} = 1.0 \text{ standard deviation}$$

Next, look up the value that corresponds to 1.0 standard deviation in a statistical table of unit normal loss integral (e.g., Levin and Kirkpatrick 1975:577). This value is 0.08332. Third, calculate the expected loss by multiplying the unit loss, the standard deviation, and the table value:

$$\$15\,000\,000 \times 4 \times 0.08332 = \$4\,999\,200$$

or about \$5 million. This value is an estimate of what is at risk in providing pileated woodpecker habitat, given the uncertainty (standard deviation) in estimating habitat capability, for this particular project. The manager can compare this value with the expected revenue derived from the timber harvest project, and decide on a course of action.

If we had perfect information, we could conduct projects that reduce habitat capability down to, but not below, the break even objective of six pairs. However, with imperfect information, the range of one standard deviation might fall below the break even point even if the expected value of habitat capability is above it. This calls for caution in conducting projects that irretrievably reduce habitat capability, unless the response of the population is known more precisely. (Remember that one fundamental tenet of the adaptive management process is that options are available for reallocating the land base.)

Now, what if a research contract could be issued to inventory pileated woodpeckers within the proposed project area and to evaluate their local habitat conditions? Let us say such a research contract would cost \$100 000 and would double our precision of estimating population response, thus cutting the standard deviation of our habitat capability estimate roughly in half, from 40 to 20% of expected values. If the expected value is currently 10 pairs, then the standard deviation would decrease from 4 to 2 pairs. Is the new information worth \$100 000?

Evaluating the expected value of the new information is a three-step process. First, determine how many standard deviations there are between the present expected habitat capability for pileated woodpeckers (10 pairs) and the break even point management objective (6 pairs), using the standard deviation expected to result from the new study:

$$\frac{10 \text{ pairs} - 6 \text{ pairs}}{2 \text{ pairs}} = 2.0 \text{ standard deviations}$$

Second, look up the unit normal loss integral corresponding to 2.0 standard deviations. This value is 0.008491. Third, calculate the expected loss by multiplying the unit loss, the expected new standard deviation, and the table value:

$$\$15\,000\,000 \times 2 \times 0.008491 = \$254\,730$$

Thus, the expected loss of the research contract, should it fail to provide us with twice the precision of estimating habitat capability, is about \$250 000. This is a reduction in loss from the previous amount — a saving of about:

$$\$5\,000\,000 - \$250\,000 = \$4\,750\,000$$

Since we can capture this potential saving by expending only \$100 000 for the research contract, we should conduct the research; the potential value of the new information is worth the cost. Eventually, however, the value of new information will be worth less and less as our initial estimates of habitat capability become more and more precise.

Decision tree analysis. Another approach to risk assessment is decision tree analysis. A decision tree is a diagram that represents all possible combinations of environmental responses and decisions that can be made over time. Decision tree analysis can be used, for example, in evaluating habitat conditions for managing habitats and maintaining viable wildlife populations (Bentley and Kaiser 1967; Nnaji *et al.* 1983; Maguire 1986; Maguire *et al.* 1987; Marcot¹).

A decision tree consists of outcomes and decision points. Outcomes are depictions of possible responses by the biological system and estimates of probabilities associated with each outcome. An example is the likelihood of wildfire in particular kinds of forest stands. Decision points are alternative actions that could be taken, such as ways to deal with wildfire. Different decisions entail different costs, such as a zero direct cost associated with letting the fire burn, or a high direct cost associated with maximum fire control efforts. Decisions, in turn, can affect probabilities of outcomes. For example, doing nothing might greatly increase the likelihood of a severe fire.

A decision tree is evaluated for the best sequence of management decisions by weighting the costs of each decision with the expected outcomes. The best decision at any one point in the tree is that with the lowest cost and greatest probability of favorable outcome. Variations in probabilities and cost parameters can also be analyzed in decision trees in more complex sensitivity assessments. See Levin and Kirkpatrick (1975) and Marcot² for decision tree analysis procedures.

Other decision-theoretic models of uncertainty. A number of other models that account for uncertainty can be used to aid environmental assessments and decision-making. One such approach is simulation modeling with random variables representing uncertain factors (Gordon 1978; Law and Kelton 1982). Simulation models have been used to evaluate habitat reserves (Rapoport *et al.* 1986); Buechner 1987), stand growth (Curtis *et al.* 1981), demographic characteristics of populations (Maguire *et al.* 1988; North *et al.* 1988), and management of populations (Rabinovich *et al.* 1985).

Other decision-theoretic approaches to dealing with uncertainty include loss-minimization analysis, marginal analysis, and conditional probability assessments (Levin and Kirkpatrick 1975; Hillier and Lieberman 1980). Bayesian statistics are also useful for synthesizing and representing incomplete knowledge (Mangel and Clark 1982; Morawski 1989b). Bayesian statistics form the basis of pattern recognition (PATREC) models used to evaluate wildlife-habitat relationships (Williams *et al.* 1977; Kirkman *et al.* 1984). For more on Bayesian statistics, see Hillier and Lieberman (1980), Jaynes 1986, Denning 1989 and Morawski 1989a.

3.5 Modeling Resource Effects with Expert Systems

One major tool for assessing the effects of projects on resources is the development and use of expert systems (Marcot 1986b; Marcot *et al.* 1988). An expert system is a computer program that reasons like a human expert to solve a narrowly defined problem. Expert systems are being developed in a wide variety of areas in natural resource management, including geobased information systems, remote sensing, wildlife habitat management, forestry and silviculture, road construction, and fire management (Stock 1987).

¹ Marcot, B.G. Use of decision tree analysis for assessing wildlife-silviculture relationships. Manuscript submitted for publication.
² *Ibid.*

Expert systems can help solve a variety of problems relevant to making land management evaluations and decisions (Table 2). They can be useful for helping to classify habitats, diagnose environmental conditions, interpret environmental data, predict habitat and population responses, and monitor conditions.

TABLE 2. Kinds of tasks suitable for expert systems in land management evaluations and decisions

Kind of task	Example
Classification	Classifying habitat types
Diagnosis	Evaluating environmental conditions and identifying circumstances requiring amelioration
Interpretation	Assessing habitat conditions in the context of specific management objectives
Prediction	Projecting wildlife population response to habitat conditions; also, projecting habitat conditions resulting from management alternatives
Monitoring	Checking if habitat (or wildlife population) conditions assumed to result from specific vegetation manipulations actually occur; also, identifying when vegetation manipulations occur that violate standards and guidelines
Design	Recommending amounts and configurations of habitats that would meet stated objectives
Planning	Recommending project activities and their scheduling that would produce desired habitat conditions
Debugging	Evaluating ongoing activities to determine those most likely causing adverse effects
Repair	Recommending ameliorative actions to reduce adverse environmental impacts or to restore conditions
Instruction	Tutoring of apprentice resource managers on project evaluation and environmental impact assessments
Control	Recommending a reevaluation of management direction based on comparing monitoring results with desired or expected conditions

To build expert systems, professional judgment is written down in a series of statements called production rules. Production rules constitute the so-called knowledge base of the expert system and are structured in an "if-then-else" format. Following is an example of a simple two-rule expert system knowledge base that evaluates pileated woodpecker habitat according to regional management requirements of the Pacific Northwest Region, USDA Forest Service:

Rule No. 1	IF	habitat is good for pileated woodpeckers
	THEN	management requirements are being met
	ELSE	requirements are not met
Rule No. 2	IF	≥45 snags at least 20 inch DBH occur within 300+ acres
	AND	≥2 snags/acre at least 10 inch DBH occur within the same 300-acre area,
	AND	1 core area of mature or old growth forest occurs per 12000–13000 acres of land,
	AND	there is a 300-acre core area of mature or old-growth forest in 1 block
	OR	in stands ≥50 acre each
	AND	each separated by <0.25 mile,
	THEN	habitat is good for pileated woodpeckers (0.8).

In this simple knowledge base, the IF portion of the first rule would be tested initially. The logical portion of the expert system — the "inference engine" — would then skip down the rules to see whether the IF portion of the first rule can be solved by some other rule. In this case, the second rule can be used in this way. That is, the THEN portion of the second rule solves for the IF portion of the first rule. In this way, the first rule acts as a "control rule," guiding the sequence of what the system asks of the user. Thus, the expert system would begin by querying the user for values for the IF portion of the second rule. Eventually, if all conditions are met, the second rule would conclude that habitat is good for pileated woodpeckers. This conclusion would then be passed back to the IF portion of the first rule, which in turn would conclude that

management requirements are being met. The ELSE portion of the first rule — that management requirements are not met — would be displayed if any of the conditions in the second rule fail. A well-structured knowledge base consisting of such production rules can harbor a great deal of knowledge on a specific topic (Pedersen 1989).

Furthermore, such an expert system can incorporate an explanation facility. With this feature, at any time in the query process, the user can ask "why?" and the system responds by showing the rules it is currently trying to verify and by further explaining the logic and source references used to build the rules in the first place. Of course, the references and logic structure had to have been first explicitly created by the expert.

Note the inclusion of a likelihood factor (0.8) in the THEN portion of the second rule. Likelihood factors can have a variety of meanings in expert systems. In this hypothetical example, the 0.8 might refer to results of a monitoring study that showed that 80% of all sites conforming to the criteria in rule 2 were occupied by pileated woodpeckers. If such empirical data are lacking, likelihood factors can also represent human experts' best professional judgment as to how often conditions provide correct outcomes.

This example demonstrates that management standards for establishing and assessing habitat conditions can be formalized into an expert system format. The main point is that most biological evaluations, planning guidelines, and management assessments can be written down similarly as a set of expert system-type rules. Ultimately, the rules are just statements of how we think biological systems — habitats and populations — will respond to our management manipulations. The rules derive from a combination of scientific data, ecological theory, professional judgment, and, in some cases, personal experience. The challenge is to articulate rules explicitly so they can be shared, tested, and refined.

An example is the expert system by McNay *et al.* (1987) that evaluates habitat conditions for black-tailed deer (*Odocoileus hemionus*) in coastal British Columbia. The expert system helps identify important black-tailed deer habitat. This helps the manager tailor activities commensurate with providing deer habitat and avoiding conflicts with competing uses. The rules in the system are derived from a combination of field research on deer use of habitats, ecological theory on value of various forest structures to ungulates, and professional judgment and personal experience on ranking the importance of various habitat conditions.

An area related to expert systems is that of intelligent databases. These are data banks with rules implanted in them to help the user recognize patterns in the data and to flag specific conditions. For example, an intelligent database might consist of a habitat inventory data file in a geographic information system depicting stand conditions for a variety of species. The intelligent portion of the database might be rules that tally the area extent of particular scarce or declining habitats. The system would send a message to the user when such habitats drop to or below threshold levels within particular watersheds.

The advantages of expert systems and intelligent databases lie in their capability to synthesize heuristic knowledge (professional and personal) with precise data. These systems are most useful for narrowly defined problems with answers that are specific and recognizable, but not necessarily mutually exclusive. An example of a problem well suited to an expert system approach is: what logging systems can be used to help maintain standing and down wood, given site-specific conditions of topography, soils, and management objectives for a particular watershed?

Expert systems are typically programmed by a "knowledge engineer" who takes information from the experts and writes the computer program to mimic their reasoning. Sometimes experts adept in computers can themselves write an advisory system. A key question in developing expert systems is: Who should provide the expert knowledge? Typically, only one expert at a time contributes to development of an advisory system. Using multiple experts may result in conflicting logic or advice. However, approaches such as the Delphi technique (Zuboy 1981; Richey *et al.* 1985a, 1985b; Schuster *et al.* 1985) exist for combining knowledge from multiple experts.

Validation of an expert system, as with most models, is a difficult and often costly process. It is especially difficult to validate the combination of statistical facts and heuristic judgment that constitutes a typical knowledge base. The best approach is to validate parts of the system — each rule or small sets of rules that can be treated more or less independently. Validation entails defining specific criteria such as

robustness, generality, accuracy, and precision, by which performance of the system will be evaluated. Rauscher (1987) recommended that useful knowledge meet four criteria: relevance, validity, timeliness, and reliability. For more on model and expert system validation, see Lancia *et al.* (1982), Marcot (1987) and Bunnell (1989).

Rauscher (1987) reviewed the use of knowledge-based tools. He recommended that a new type of "knowledge processor" be developed that manages chunks of information and their relationships. Links between information chunks provide useful ways to synthesize and condense knowledge. Such a system would force information to be written down explicitly, serving to highlight the presence of, and gaps in, known facts.

In the future, knowledge bases will be developed to complement current, simpler databases. Rauscher's "knowledge processors," including expert systems and intelligent databases, will be maintained by domain-specific experts who compile, update, and abstract specific areas of expertise (Menzies 1989). Eventually, knowledge systems may surpass humans in capacity and capability for evaluating conditions, raising interesting ethical and political questions (deGaris 1989). At present, progress is being made in developing logical computer programs that can reason under ambiguous evidence and that combine useful approaches from decision theory and expert systems alike (Langlotz and Shortliffe 1989).

3.6 Where Can Information Go Wrong?

Thus far, emphasis has been on positive aspects of combining kinds of information for making biological evaluations, accounting for uncertainty, developing advisory tools, and making land management decisions. There are pitfalls too. Incomplete or uncertain information can misguide as well as inform. Also, use of professional judgment and, especially, personal experience can be fraught with bias. One good solution is to seek peer review of evaluations, guidelines, and decisions that are based heavily on incomplete or uncertain information or on personal knowledge.

Using evaluation tools outside the scope in which they were built carries risks of error. This applies to prediction models of wildlife-habitat relationships, as well as to standards and guidelines for habitat management. Also, applying ecological theory and professional judgment outside contexts in which they evolved might be a formula for error, although the expert should know where and where not to extrapolate such information.

Johnson *et al.* (1985) argue that the degree of accuracy of information used in modeling depends on the objectives, but that generally trustworthy data are essential for use in management. They illustrated how assumptions drawn from a model on canvasback ducks (*Aythya valisineria*) were not supported by biological evidence. Use of such a model could greatly misguide management of the species. Models used for management should be based on as reasonable and realistic hypotheses as possible. Thorough biological examinations of underlying assumptions should be conducted of any model used for guiding resource management.

4 COMBINING DATA, EXPERIENCE, AND PROFESSIONAL JUDGMENT: A CASE STUDY

This section provides an example of building a set of management guidelines from various sources of information. The example used is the development of guidelines for a problem in integrated forest-wildlife management. Specifically, the guidelines are intended to provide forest and down wood habitat for a guild of small mammals that disperse spores of underground fungi important for maintaining the trophic health of the forest ecosystem. The example illustrates: 1) how to approach solving a problem combining data, experience, and professional judgment; 2) where each kind of information enters the process; and 3) how to identify key assumptions for further testing and monitoring. The section ends with a series of questions to be addressed when data and experience are combined in this manner.

4.1 The Case Study: Providing Habitat for Mycophagous Mammals

In this scenario, we are interested in providing habitat for a guild of small mammals sharing a common trait of mycophagy, that is, eating underground-fruited (hypogeous) fungi. In British Columbia, Washington, and Oregon, some nine species regularly engage in mycophagy (Table 3), including four squirrels or chipmunks, three voles, and two jumping mice. For summaries of life histories, see Ingles (1965), Maser *et al.* (1981), Chapman and Feldhamer (1982), and Mathews (1988). Brown (1985) provides information on general habitat relationships.

TABLE 3. Mycophagous (hypogeous fungus-eating) small mammals (Rodentia) of the Pacific Northwest

Sciuridae
Townsend chipmunk (<i>Eutamias townsendi</i>)
yellow pine chipmunk (<i>Eutamias amoenus</i>)
western gray squirrel (<i>Sciurus griseus</i>)
northern flying squirrel (<i>Glaucomys sabrinus</i>)
Cricetidae
California red-backed vole (<i>Clethrionomys californicus</i>)
Gapper vole (<i>Clethrionomys gapperi</i>)
Oregon or creeping vole (<i>Microtus oregoni</i>)
Zapodidae
jumping mouse (<i>Zapus princeps</i>)
Pacific jumping mouse (<i>Zapus trinotatus</i>)

The management guidelines should provide sufficient habitat conditions for maintaining viable populations of each species of this mycophagous guild. More specifically, the guidelines should prescribe the type, amount, and distribution of habitat conditions, particularly down wood, needed to maintain well-distributed populations of each species. While this example will not provide such guidelines *per se*, it will demonstrate the process of considering available information and identifying key assumptions.

4.2 What Is at Risk?

The interest in this example arose from recent studies on how hypogeous fungi, especially mycorrhizae, help maintain health of coniferous trees of commercial and ecological value, including pines (*Pinus* spp.), hemlocks (*Tsuga* spp.), spruces (*Picea* spp.), true firs (*Abies* spp.), Douglas-fir (*Pseudotsuga menziesii*), oaks (*Quercus* spp.), and alders (*Alnus* spp.) (Bartels *et al.* 1985). Mycophagous rodents are important dispersers of spores of these fungi, and down wood plays a major role in providing habitat for this small mammal guild (Maser *et al.* 1978; Maser and Trappe 1984).

Down wood also provides sites for nutrient accumulation, nitrogen fixation by nonsymbiotic bacteria (Maser *et al.* 1984; Cromack 1988), habitats for a variety of other wildlife species, and regeneration sites for

tree seedlings such as western hemlock (*Tsuga heterophylla*), and helps stabilize soils on slopes. These additional roles of down wood contribute to maintaining long-term productivity of forests in the Pacific Northwest.

What are the costs and benefits of implementing guidelines for a mycophagous mammal guild? Such a set of guidelines would not be without trade-offs. Without guidelines, project activities such as site-specific treatments for timber production (clearcutting, slash piling and burning, scarification, etc.) might inadvertently reduce or eliminate suitable microhabitats and resources for the species. Once the guild is locally eliminated, long-term site productivity might be much reduced.

On the other hand, with guidelines, some resources (e.g., standing or down wood) might need to be retained on most project sites. Alternatively, some portion of the landscape might need to be left in suitable habitat (unharvested mature or old-growth stands). This might entail reduction in productivity of some forest resources such as timber.

4.3 Guidelines for Maintaining the Mycophagous Guild

What information would be needed for developing management guidelines? At the least, the following assessments would be essential:

1. forest types, ages, and structures in which each small mammal species finds suitable habitat;
2. distribution of habitats to ensure that the guild would transport beneficial fungal spores among forest stands throughout the landscape;
3. specific microhabitat components, especially type, amount, and distribution of down wood, that contribute to suitable habitat for each small mammal species;
4. degree to which species of this guild contribute to maintaining health of forest stands, such as effects on stand volume growth or increased survival of trees; and
5. population numbers, densities, and distributions of each species of this guild necessary for ensuring their long-term continued existence, well distributed across the landscape.

What information is available to conduct these assessments? First, available **scientific data** on species life histories and studies of habitat relationships can begin to address items (1) and (3) on habitat attributes. However, no published studies to date have quantified specific stand structures for each species. Rather, the literature (e.g., Brown 1985) addresses general forest types in which each species is expected to be found.

There are no published scientific studies quantifying items 2, 4, and 5 for these species. Instead, one would have to rely on the use of **ecological theory** for these assessments. For example, assessing the arrangement of forest habitats needed to maintain well-distributed populations could be based on an understanding of each species' specific habitat requirements and its dispersal capabilities through a variety of habitat types. Spatial models simulating dispersal through patchy habitats would be helpful for assessing effects of forest stand configurations (e.g., Chesson 1981; Bovet and Benhamou 1988; Fahrig and Paloheimo 1988; Murray 1988; Hastings and Wolin 1989). The guidelines could place suitable habitats, of sufficient amounts to maintain local breeding populations, no further than each species' effective dispersal distance (e.g., see Gliwicz 1988). Effects of fragmentation of forest stands could also be assessed (Quinn and Hastings 1987; Wilcove 1987). This is an example of using ecological concepts rather than direct scientific data.

Similarly, item 5, assessing population sizes and distributions contributing to long-term viability, could entail use of current concepts and theory on population dynamics and extinction probabilities (e.g., see Reed *et al.* 1986; Soule 1987; Burgman *et al.* 1988; Iwasa and Mochizuki 1988; Maguire *et al.* 1988; Harris and Allendorf 1989; and see Shaffer 1981 for basic concepts of factors affecting population viability). Demographic models (e.g., Slade and Levenson 1982) can be used to estimate population trends and extinction probabilities. Similar demographic assessments have been conducted for grizzly bears (*Ursus arctos horribilis*) in the Yellowstone ecosystem (Knight and Eberhardt 1984).

From a theoretical perspective, other factors might be taken into account, including effects of environmental fluctuations on population stability (Lande and Orzack 1988; Pease *et al.* 1989), behavior (Tamarin 1988), and effects of disease (May 1988).

Neither scientific data nor ecological theory would offer sufficient information to implement the general guidelines. Thus, **professional judgment** and **personal experience** will be necessary. For example, the guidelines might specify the proportion of a general forest landscape that should contain suitable forest stages, and type, amount, and distribution of down wood to be provided. However, how these guidelines are carried out operationally is dependent on professional experience with, and personal understanding of, forest management activities.

4.4 Key Assumptions

Key assumptions for monitoring and testing would be those based on extrapolations from ecological theory and those based on professional judgment and personal experience. Such tests might include assessing expected presence and densities of small mammal populations assumed to be provided by forest stands, and specific amounts and distributions of down wood. They might also include comparing empirical yield tables in landscapes with and without the guidelines applied. Information based on scientific data, such as life histories of each species, would not require testing.

4.5 Questions to Address

When data and experience are being combined, a general set of questions can be asked to help guide development, monitoring, and evaluation of guidelines:

Questions about effects of uncertain or incomplete information.

1. What available information is the "softest" or most uncertain? Why?
2. How does this specifically affect devising, evaluating, and implementing these standards and guidelines? How would you use such information in an advisory system?
3. What additional information, aside from that on the biology or ecology of the species, is needed to make an "informed decision?" Why?

Questions about developing guidelines despite incomplete information.

1. What additional information on the biology or ecology of the species is needed? Why?
2. In question (1), how do you assess "need"? How would you know or evaluate which additional information is worth spending money on?
3. Can you, and should you, proceed with developing standards and guidelines with currently available information? Why or why not? What assumptions and evaluations would this entail?
4. What are the ramifications if you do not develop standards and guidelines at this time? If you do? How would you go about evaluating such ramifications?

Questions about filling in the blanks of knowledge.

1. Whether or not standards and guidelines are currently implemented, how would you decide what additional information needs to be gathered? How would you set priorities?
2. If standards and guidelines are to be currently implemented, how would you identify additional information needed for testing or revising them?
3. How would you gather additional, needed information? Would scientifically designed field studies provide all necessary information? If not, what else would be needed?

Questions about development and use of evaluation tools.

1. What tools would you develop for evaluating alternative forms of standards and guidelines?
2. What specific parameters would be assessed by the tools devised in question (1)? How would the tools be structured?

3. Given available information, which parameters (from question 2) could you currently derive from hard facts, and which from softer expert judgment and personal experience?
4. Is information derived from personal experience, statistical data, ecological theory, and professional judgment substantially different in usefulness? How so? (Define "usefulness": legally, scientifically, administratively, etc.) How would this affect your evaluations of the tool?

Questions about implementing and evaluating plans.

1. How would you evaluate the standards and guidelines? (Hint: use evaluation criteria such as practicality, acceptability, implementation, effects on site productivity, etc.)
2. What would you monitor and why?
3. What specific aspects of the standards and guidelines would you likely reevaluate after the monitoring information was gathered, and why?
4. What roles do personal knowledge, scientific facts, ecological theory, and professional judgment play in such reevaluations?

5 SUMMARY AND CONCLUSIONS

Four main kinds of information are generally used to solve a problem in integrated resource management: scientific data, ecological theory, professional judgment, and personal experience. These kinds of information are often combined in biological evaluations and resource decision-making. Professional judgment and personal experience are relied on more heavily when scientific information is more uncertain.

Methods of evaluating uncertainty include assessments of expected value of perfect or sample information; decision-tree analysis; and a host of other methods from decision theory and risk analysis. Articulating biological assessments and resource management guidelines in an expert system format of knowledge rules can also help clarify what is known and what is derived from theory or judgment. Such an approach helps one articulate key assumptions in evaluations, guidelines, and decisions.

Uncertainty of knowledge should not preclude decision-making. However, critical assumptions and extrapolations should be made explicit. They can be tested under an adaptive management paradigm if measurable parameters and feasible field methods are identified, re-evaluation criteria are specified, and management options are available.

When management guidelines are being devised and resource decisions made, it is helpful to consider key questions about the sources of information used, their reliability, and the ramifications (costs, benefits, and risks to the resources) of proceeding in light of uncertain information.

LITERATURE CITED

- Bartels, R., J.D. Dell, R.L. Knight, and G. Schaefer. 1985. Dead and down woody material. *In* Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 1 - Chapter narratives. E.R. Brown (editor). USDA For. Serv., Pac. NW Region, Portland, Ore. pp. 171-186.
- Bentley, W.R. and H.F. Kaiser, Jr. 1967. Sequential decisions in timber management: a Christmas tree case study. *J. For.* (Oct.):714-719.
- Bovet, P. and S. Benhamou. 1988. Spatial analysis of animals' movements using a correlated random walk model. *J. Theor. Biol.* 131(4):419-433.
- Brown, E.R. (editor). 1985. Management of wildlife and fish habitats in forests of western Oregon and Washington. 2 vols. USDA For. Serv., Pac. NW Region, Portland Ore. 332 p.
- Buechner, M. 1987. Conservation in insular parks: simulation models of factors affecting the movement of animals across park boundaries. *Biolog. Conserv.* 41:57-76.
- Bunnell, F.L. 1989. Alchemy and uncertainty: what good are models? USDA For. Serv., Portland, Ore. Gen. Tech. Rep. PNW-GTR-232. 27 p.
- Burgman, M.A., H.R. Akcakaya, and S.S. Loew. 1988. The use of extinction models for species conservation. *Biol. Conserv.* 43(1):9-25.
- Chapman, J.A. and G.A. Feldhamer. 1982. Wild mammals of North America. Johns Hopkins Univ. Press, Baltimore, Md.
- Chesson, P.L. 1981. Models for spatially distributed populations: the effect of within-patch variability. *Theor. Pop. Biol.* 19:288-325.
- Cromack, K. 1988. Nutrient cycling in old-growth forests. Presented at Old-growth forests of the Pacific Northwest, August 22-26, 1988, Ore. State Univ., Corvallis, Ore. Sponsored by College of Forestry at Oregon State University and the International Union of Forestry Research Organizations.
- Curtis, R.O., G.W. Clendenen, and D.J. DeMars. 1981. A new stand simulator for coast Douglas-fir: DFSIM user's guide. USDA For. Serv., Washington, D.C. Gen. Tech. Rep. PNW-128. 79 p.
- de Garis, H. 1989. What if AI succeeds? The rise of the twenty-first century artefact. *AI Magazine* 10(2):17-22.
- Denning, P.J. 1989. Bayesian learning. *Amer. Scientist* 77:216-218.
- Fahrig, L. and J. Paloheimo. 1988. Effect of spatial arrangement of habitat patches on local population size. *Ecology* 69:468-475.
- Gliwicz, J. 1988. The role of dispersal in models of small rodent population dynamics. *Oikos* 52(2):219-221.
- Gordon, G. 1978. System simulation. 2nd ed. Prentice-Hall, Englewood Cliffs, N.J. 324 p.
- Harris, R.B., and F.W. Allendorf. 1989. Genetically effective population size of large mammals: an assessment of estimators. *Conserv. Biol.* 3(2):181-191.
- Hastings, A. and C.L. Wolin. 1989. Within-patch dynamics in a metapopulation. *Ecology* 70:1261-1266.
- Hillier, F.S. and G.J. Lieberman. 1980. Introduction to operations research. 3rd ed. Holden-Day, San Francisco, Cal. 829 p.
- Ingles, L.G. 1965. Mammals of the Pacific states. Stanford Univ. Press, Stanford, Cal. 506 p.
- Iwasa, Y. and H. Mochizuki. 1988. Probability of population extinction accompanying a temporary decrease of population size. *Res. Popul. Ecol.* 30:145-164.
- Jaynes, E.T. 1986. Bayesian methods: general background. *In* Maximum entropy and Bayesian methods in applied statistics. J.H. Justice (editor). Cambridge Univ. Press, Cambridge, England, pp. 1-25.

- Johnson, D.H., M.J. Conroy, and J.D. Nichols. 1985. The need for accuracy in modelling: an example. *Ecological Modelling* 30:157-161.
- Kirkman, R.L., J.A. Eberly, W.R. Porath, and R.R. Titus. 1984. A process for integrating wildlife needs into forest management planning. *In* *Wildlife 2000 modeling habitat relationships of terrestrial vertebrates*. J. Verner, M.L. Morrison, and C.J. Ralph (editors). Univ. Wisconsin Press, Madison, Wis., pp. 347-350.
- Knight, R.R. and L.L. Eberhardt. 1984. Projected future abundance of the Yellowstone grizzly bear. *J. Wildl. Manage.* 48:1435-1438.
- Lancia, R.A., S.D. Miller, D.A. Adams, and D.W. Hazel. 1982. Validating habitat quality assessment: an example. *Trans. N. Amer. Wildl. Nat. Res. Conf.* 47:96-110.
- Lande, R. and S.H. Orzack. 1988. Extinction dynamics of age-structured populations in a fluctuating environment. *Proc. Nat. Acad. Sci. USA* 85(19):7418-7421.
- Langlotz, C.P. and E.H. Shortliffe. 1989. Logical and decision-theoretic methods for planning under uncertainty. *AI Magazine* 10(1):39-47.
- Law, A.M. and W.D. Kelton. 1982. *Simulation modeling and analysis*. McGraw-Hill, New York, N.Y. 400 p.
- Levin, R.I. and C.A. Kirkpatrick. 1975. *Quantitative approaches to management*. 3rd ed. McGraw-Hill, New York, N.Y. 586 p.
- McNay, R.S., R.E. Page, and A. Campbell. 1987. Application of expert-based decision models to promote integrated management of forests. *Trans. N. Amer. Wildl. Nat. Resour. Conf.* 52:82-91.
- Maguire, L.A. 1986. An analysis of augmentation strategies for grizzly populations: the Cabinet-Yak Ecosystem as an example. *Rep. to USDA For. Serv., Contract No. 40-3187-4-1748*. 36 p.
- Maguire, L.A., U.S. Seal, and P.F. Brussard. 1987. Managing critically endangered species: the Sumatran rhino as a case study. *In* *Viable populations for conservation*. M.E. Soule (editor). Cambridge Univ. Press, Cambridge, Mass. pp. 141-158.
- Maguire, L.A., M.L. Shaffer, and A.R. Tipton. 1988. Stochastic population simulation. *Conserv. Biol.* 2:6-7.
- Mangel, M. and C.W. Clark. 1982. Uncertainty, search, and information in fisheries. *Univ. B.C. Inst. Applied Mathematics and Statistics, Vancouver, B.C. Tech. Rep. No. 82-6*, 40 p.
- Marcot, P.G. 1986a. Concepts of risk analysis as applied to viable population assessment and planning. *In* *The management of viable populations: theory, applications, and case studies*. B.A. Wilcox, P.F. Brussard, and B.G. Marcot (editors). Center for Conservation Biology, Stanford, Cal.
- . 1986b. Use of expert systems in wildlife-habitat modeling. *In* *Wildlife 2000: modeling habitat relationships of terrestrial vertebrates*. J. Verner, M.L. Morrison, and C.J. Ralph (editors). Univ. of Wisconsin Press, Madison, Wis., pp. 145-150.
- . 1987. Testing your knowledge base. *AI Expert* 2:42-47.
- Marcot, B.G., R. Holthausen, and H. Salwasser. 1986. Viable population planning. *In* *The management of viable populations: theory, applications, and case studies*. B.A. Wilcox, P.F. Brussard, and B.G. Marcot (editors). Center for Conservation Biology, Stanford, Cal.
- Marcot, B.G., R.S. McNay, and R.E. Page. 1988. Use of microcomputers for planning and managing silviculture-habitat relationships. *USDA For. Serv., Pac. NW Regions, Portland, Oreg. Gen. Tech. Rep. PNW-GTR-228*. 19 p.
- Maser, C., B.R. Mate, J.F. Franklin, and C.T. Dymess. 1981. *Natural history of Oregon Coast mammals*. USDA For. Serv., Gen. Tech. Rep. PNW-133.
- Maser, C. and J.M. Trappe. 1984. *The seen and unseen world of the fallen tree*. USDA For. Serv., Pac. NW For. Range Exp. Sta., Portland, Oreg. Gen. Tech. Rep. PNW-164. 56 p.

- Maser, C., J.M. Trappe, and C.Y. Li. 1984. Large woody debris and long-term forest productivity. Proc., Pacific Northwest Bioenergy Systems: Policies and Applications. May 10-11, 1984, Portland, Oreg.
- Maser, C., J.M. Trappe, and D.C. Ure. 1978. Implications of small mammal mycophagy to the management of western coniferous forests. Trans. N. Amer. Wildl. Nat. Res. Conf. 43:78-88.
- Mathews, D. 1988. Cascade-Olympic natural history. Raven Editions, Portland Audubon Society, Portland, Oreg. 625 p.
- May, R.M. 1988. Conservation and disease. Conserv. Biol. 2:28-30.
- Menzies, T. 1989. Domain-specific knowledge representation. AI Expert 4(6):36-45.
- Morawski, P. 1989a. Programming Bayesian belief networks. AI Expert 4(8):75-79.
- . 1989b. Understanding Bayesian belief networks. AI Expert 4(5):44-48.
- Murray, J.D. 1988. Spatial dispersal of species. Trends Ecol. Evol. 3(11):307-309.
- Nnaji, S., J.S. Fisher, and S.V. Shabica. 1983. An application of decision analysis to shoreline management. J. Environ. Manage. 17:35-46.
- North, P.M., A.W. Boddy, and D.R. Forrester. 1988. A computer simulation study of stochastic models to investigate the population dynamics of the screech owl (*Otus asio*) under increased mortality. Ecological Modeling. 40(3/4):233-263.
- Pease, C.M., R. Lande, and J.J. Bull. 1989. A model of population growth, dispersal, and evolution in a changing environment. Ecology 70:1657-1664.
- Pedersen, K. 1989. Well-structured knowledge bases. AI Expert 4(4):44-55.
- Polanyi, M. 1962. Personal knowledge. Univ. Chicago Press, Chicago, Ill. 428 p.
- Quinn, J.F. and A. Hastings. 1987. Extinction in subdivided habitats. Conserv. Biol. 1:198-209.
- Rabinovich, J.E., M.J. Hernandez, and J.L. Cajal. 1985. A simulation model for the management of vicuna populations. Ecological Modelling 30:275-295.
- Rapoport, E.H., G. Borioli, J.A. Monjeau, J.E. Puntieri, and R.D. Oviedo. 1986. The design of nature reserves: a simulation trial for assessing specific conservation value. Biol. Conserv. 37:269-290.
- Rauscher, H.M. 1987. Increasing scientific productivity through better knowledge management. AI Applications 1(2):21-31.
- Reed, J.M., P.D. Doerr, and J.R. Walters. 1986. Determining minimum population sizes for birds and mammals. Wildl. Soc. Bull. 14:255-261.
- Richey, J.S., B.W. Mar, and R.R. Horner. 1985a. The Delphi technique in environmental assessment. I. Implementation and effectiveness. J. Environ. Manage. 21:135-146.
- Richey, J.S., R.R. Horner, and B.W. Mar. 1985b. The Delphi technique in environmental assessment. II. Consensus on critical issues in environmental monitoring program design. J. Environ. Manage. 21:147-159.
- Romesburg, H.C. 1981. Wildlife science: gaining reliable knowledge. J. Wildl. Manage. 45:293-313.
- Schuster, E.G., S.S. Frissell, E.E. Baker, and R.S. Loveless. 1985. The Delphi method: application to elk habitat quality. USDA For. Serv., Res. Paper INT-353. 32 p.
- Shaffer, M.L. 1981. Minimum population sizes for species conservation. BioScience 31:131-134.
- Slade, N.A. and H. Levenson. 1982. Estimating population growth rates from stochastic Leslie matrices. Theoretical Population Biology 22:299-308.
- Soule, M.E. 1987. Viable populations for conservation. Cambridge Univ. Press, Cambridge, Mass. 189 p.
- Stock, M. 1987. AI and expert systems: an overview. AI Applications in Natural Resource Manage. 1(1):9-17.

- Tamarin, R.H. 1988. The role of behavior in models of small rodent population dynamics. *Oikos* 52(2):222-223.
- Walters, C.J. and Hilborne, R. 1976. Adaptive control of fishing systems. *J. Fish. Res. Board Canada*, 33:145-59.
- Walters, C.J. 1986. Adaptive management of renewable resources. MacMillan Publishing Co., New York, N.Y. 374 p.
- Wilcove, D.S. 1987. From fragmentation to extinction. *Natural Areas J.* 7:23-29.
- Williams, G.L., D.R. Russell, and W.K. Seitz. 1977. Pattern recognition as a tool in the ecological analysis of habitat. *In* Classification, inventory, and analysis of fish and wildlife habitat. U.S. Dep. Int. Fish and Wildlife Serv., FWS/OBS-78/76, pp. 521-531.
- Zuboy, J.R. 1981. A new tool for fishery managers: the Delphi technique. *N. Amer. J. Fish. Manage.* 1:55-59.